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This report summarizes and evaluates water-quality data collected at 35 stream sites in the coal region of southeastern Montana. Sarpy Creek, Armells Creek, and Rosebud Creek sometimes have dissolved-solids concentrations that cause water to be marginal for agricultural purposes. At times of rainfall and snowmelt, the runoff water mixes with the base-flow component to improve the overall quality. Water in the Tongue River generally showed a downstream degradation in which some changes were related to the lithology of the aquifers contributing water to streamflow. Water from Pumpkin Creek and Mizpah Creek is used mostly for cattle watering. To some extent water is used for irrigation although the salinity hazard was often high. The chemical quality of the Powder River changed little during flow downstream. High sediment loads of the river acted as transporting agents for many of the plant nutrients and trace-element constituents.

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WATER QUALITY OF SELECTED STREAMS IN THE COAL AREA OF SOUTHEASTERN MONTANA

By

J. R. Knapton and P. W. McKinley

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FACTORS FOR CONVERTING ENGLISH UNITS TO METRIC UNITS

The following factors may be used to convert the English units published herein to the International System of Units (SI).

Multiply English units	By	To obtain SI units
acre-feet (acre-ft)	1233	cubic meters (m^3)
acres	4047	square meters (m^2)
	.4047	hectares (ha)
cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
feet (ft)	.3048	meters (m)
feet per mile (ft/mi)	.1894	meters per kilometer (m/km)
inches (in)	25.4	millimeters (mm)
miles (mi)	1.609	kilometers (km)
pound (lb)	453.6	grams (g)
square miles (mi^2)	2.590	square kilometers (km^2)
ton (short) per day (ton/day)	.9072	metric ton per day (t/d)

temperature, degrees Celsius (°C) = 0.556 (°F-32)

GLOSSARY

Alluvium. A general term for sand, silt, and mud deposited by a stream, along its banks or upon its flood plain.

Anaerobic. Designating organisms capable of living in the absence of free oxygen.

Anion. Negatively charged ion.

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Cation. Positively charged ion.

Concentration. A measure of the amount of dissolved substance contained per unit of volume.

Diel. Relating to a 24-hour period that usually includes a day and the adjoining night.

Evaporation. Process by which water escapes from water surfaces and moist soil and enters the atmosphere.

Fluvial. Produced by or pertaining to a river.

Formation. A distinct lithologic unit that may be used in geologic mapping, generally confined to bedded or stratified rocks.

Hydrograph. A graph showing stream discharge or constituent concentration of water with respect to time.

Inorganic. Designating or composed of matter that is not animal or vegetable.

In situ. Refers to measurements made at the data-collection site.

Intermittent stream. One which flows only at certain times of the year when it receives water from springs or from some surface source.

Ion. An atom or molecularly bound group of atoms which has gained or lost one or more electrons and which has thus a negative or positive charge.

Lithology. The physical character of a rock, defined by such characteristics as color, mineralogic composition, and grain size.

Mercaptan. Any of a class of chemical compounds analogous to the alcohols and characterized by the substitution of sulfur for oxygen in the OH radical.

Organic. Pertaining to compounds containing the carbon atom. For exceptions refer to inorganic.

Perennial stream. One which flows year-round.

Periphyton. The community of microorganisms that is attached to or lives upon submerged solid surfaces.

Phytoplankton. The plant part of the community of suspended or floating organisms which drift passively with water currents.

Transpiration. The process by which water escapes from the living plant, principally the leaves, and enters the atmosphere.

WATER QUALITY OF SELECTED STREAMS IN THE COAL AREA OF SOUTHEASTERN MONTANA

By

J. R. Knapton and P. W. McKinley

ABSTRACT

The prospect of large-scale development of coal in the Northern Great Plains has fostered concern about the degradation of water quality. Therefore, this report was prepared to summarize and evaluate water-quality data that have been collected over a 2-year period at 35 stream sites in the coal region of southeastern Montana. Many chemical measurements were made and some of the results are divided into categories of major dissolved constituents, plant nutrients, and trace elements. Physical measurements included water discharge, suspended sediment, and water temperature. Some of the constituent values are compared to various standards that are often used to evaluate water for different uses.

Sarpy Creek and Armells Creek are two relatively small intermittent streams that flow directly into the Yellowstone River. Both contain water having high dissolved-solids concentrations that often make it unfit for agricultural purposes. At times of snowmelt and rainfall, the runoff water mixes with the base-flow component to improve the overall quality.

Rosebud Creek originates a few miles north of the Montana-Wyoming border and flows north to the Yellowstone River. Four main-stem stations and one tributary station were located in the lower half of the drainage. Water quality changed little between the three most-upstream stations, but notable differences in major ions occurred from the third station to the mouth. The differences correlated well with stratigraphic units. Like the chemical character of the water, suspended sediment was often most variable from the third station to the mouth.

The Tongue River from the Tongue River Dam to the mouth maintains perennial flow. The Tongue River Dam modifies many of the natural water-quality conditions, creating effects on chemical and physical properties that were measured far downstream. Although the water in two major tributaries, Hanging Woman Creek and Otter Creek, was of inferior quality to that of the Tongue River, the limited quantity of streamflow caused little impact on the river. The small Tongue River tributaries had a wide range in properties but little flow except during runoff periods. Water in the Tongue River generally showed downstream degradation in which some changes were related to lithology of the aquifers discharging to streams. Suspended sediment was typified by

small to moderate concentrations in the upper stream section and pronounced increases downstream.

Pumpkin Creek is a major tributary of the Tongue River. Unlike the larger streams Pumpkin Creek often showed a significant reduction in dissolved-solids concentration from upstream to downstream and a uniformity of major ions throughout the drainage. The water was characteristically a sodium sulfate type.

The largest stream in the study area, the Powder River, was sampled at Moorhead just north of the Montana-Wyoming border and near Locate, 27 miles upstream from the mouth. The chemical quality of the river changed little between the two stations. Even though the salinity often was in the high range when classified for irrigation, the most extensive use of the water was for irrigation of hay crops in the bottomlands. Large amounts of suspended sediment acted as a transporting agent for many of the nutrients and trace element constituents. The 1975 water year was characterized by abnormally high streamflow and high sediment transport. Annual suspended-sediment discharge measured near Locate increased approximately 50 percent in comparison with Moorhead. In 1976, a year of average streamflow, the same comparison between sites showed nearly a 7-percent reduction.

Water from Mizpah Creek, a tributary of the Powder River, is used mostly for cattle watering and to some extent for irrigation. Major-ion concentrations often decreased downstream, thus improving the water quality. Suspended sediment had an important role in the transport of nutrients in Mizpah Creek, which had the highest measured values for both nitrogen and phosphorus for streams in the study area.

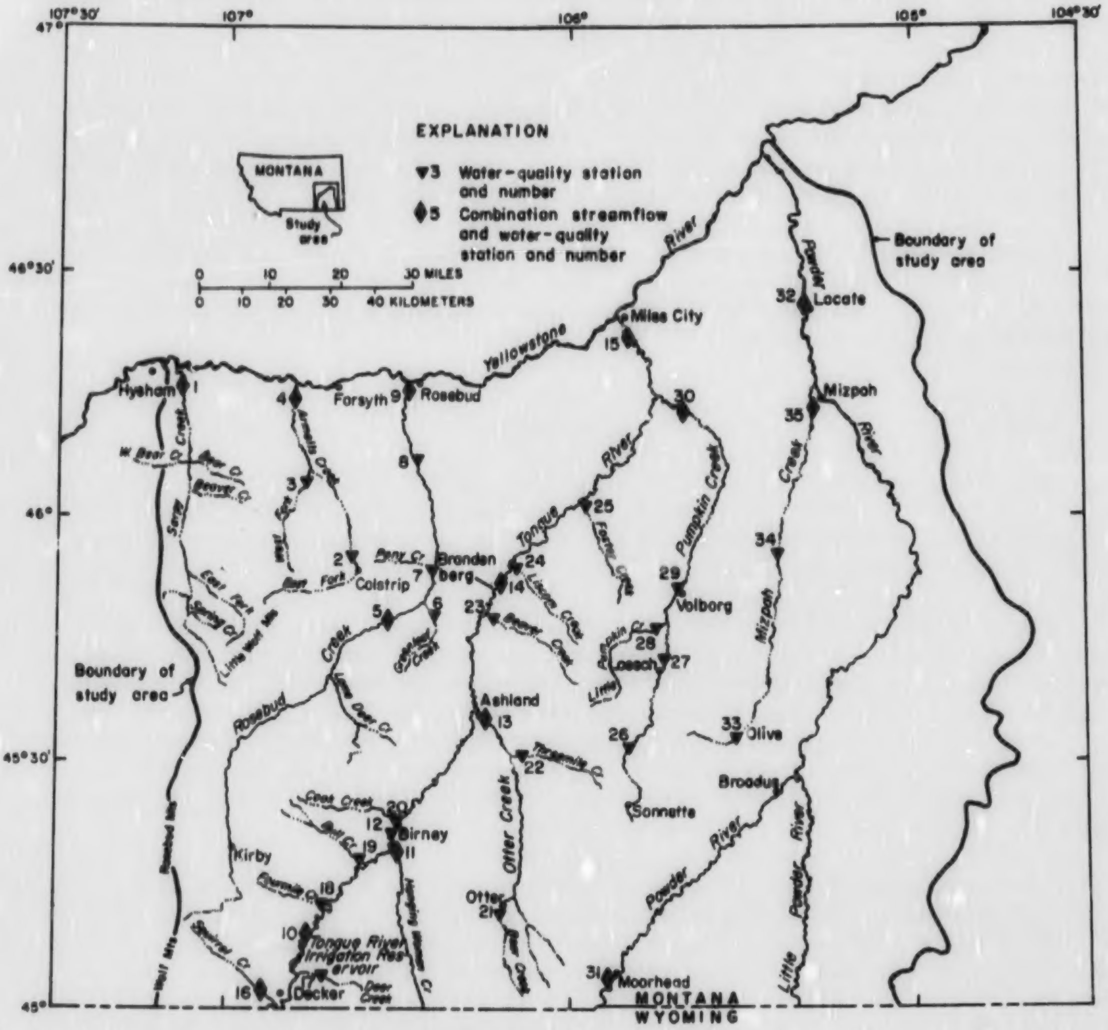
INTRODUCTION

The Northern Great Plains, because of its vast supply of low sulfur coal, is becoming increasingly important as a source of supply for meeting future energy needs. Of special significance to Montana is the area in the southeastern part of the State from the Yellowstone River to the Montana-Wyoming border--part of an area commonly referred to as the Fort Union coal region. At the present time the majority of the coal mined within the State is extracted by surface-mining methods from this area and many of the proposals for future coal mining lie here.

The prospect of large-scale development of coal has fostered concern about degradation of environmental quality--especially the quality of surface water. Major and minor streams drain the area and flow directly or indirectly into the Yellowstone River. Some of the mining sites and potential mining sites are near stream channels; many others are in locations that may not affect surface runoff into streams. However, regardless of the physical setting, activities at any of the mines may disrupt and alter the quantity and quality of ground water that will eventually be discharged to streams. In addition to actual mining practices, related activities such as population growth and economic development may pose threats to surface-water quality.

The assessment of the water resources as near to their pre-mining state as possible was deemed to be essential when it became evident that large-scale mining would become a reality. An adequate data base would make possible the verification of any water degradation and provide a basis for making necessary land-use decisions and development-impact predictions. Prior to 1974 only limited water-quality information was available for the major streams in the study area and almost no information for the smaller streams.

Thus, beginning in October 1974, a network of 35 data-collection stations was established by the U.S. Geological Survey to monitor water quality; 14 of these were continuous-recording streamflow stations (fig. 1). The Geological Survey, the U.S. Bureau of Land Management, and the Environmental



107°30'
107°
106°
105°
104°30'
47°
46°30'
46°
45°30'
45°
EXPLANATION
MONTANA
Study area
▼3 Water-quality station and number
◆5 Combination streamflow and water-quality station and number
0 10 20 30 MILES
0 10 20 30 40 KILOMETERS
Boundary of study area
Boundary of study area
Yellowstone
River
Miles City
Hysham
Forsyth
Rosebud
Colstrip
Brandenberg
Ashland
Birney
Kirby
Otter
Decker
Volborg
Loesch
Sonnette
Olive
Broadus
Moorhead
Locate
Mizpah
Tongue River
Tongue River Irrigation Reservoir
Rosebud Creek
Armells Creek
Sarpy Creek
W Bear Cr.
Bear Cr.
Beaver Cr.
East Fork
Spring Cr.
Little Wolf Mts
Wolf Mts
Rosebud Mts
Lame Deer Cr.
Greenleaf Creek
Cook Creek
Bull Cr.
Fourmile Cr.
Squirrel Cr.
Deer Creek
Hanging Woman Cr.
Otter Creek
Home Cr.
Tooley Cr.
Pumpkin Creek
Little Pumpkin Cr.
Mizpah Creek
Powder River
Little Powder River
Foster Creek
Liscom Creek
Beaver Creek
Threemile C.
MONTANA
WYOMING
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Figure 1.--Locations of study area and water-quality stations.

Protection Agency provided funds for the investigation. Additional surface-water-quality investigations were made in the area, but were short term or of limited areal extent. The Water Quality Bureau of the Montana Department of Health and Environmental Sciences collected short-term data on some streams in the study area as a supplement to the "Water Quality Inventory and Management Plan" for the middle and lower Yellowstone River basin (Karp and Botz, 1975; Karp and others, 1975).

Purpose and scope

The purpose of this report is (1) to summarize the data collected during the first 2 years (1 year for some stations) of network operation and (2) to provide a detailed description of the water quality at each data-collection station and for each drainage basin. Although the data are published by the U.S. Geological Survey (issued annually), some users will find the statistical summaries and the various graphs in this report to be of more use than the data tabulation alone. A principal objective of this report is to make the data meaningful to those without a technical background in the field of water quality. Land users, administrators, and professionals in affiliated fields are among readers who may find the report useful.

About 60 different water-quality measurements made on a routine schedule at each of the network stations are summarized in this report. The properties measured are the same as those being analyzed throughout the Northern Great Plains in similar programs.

Drainage

The study area (fig. 1) is in southeastern Montana between the Yellowstone River and the Montana-Wyoming border. Data were collected on the following streams and their tributaries: Sarpy Creek, Armells Creek, Rosebud Creek, Tongue River, and Powder River.

Sarpy Creek, Armells Creek, and Rosebud Creek originate within the study area and flow north to the Yellowstone River. Of the three streams, Rosebud Creek has the largest drainage and flows perennially from near the uplands to its mouth. Sarpy Creek and Armells Creek are intermittent throughout their upper drainages. Year-round flow, when it occurs, is confined to near the mouths. For these streams and the many small tributaries to the Tongue and Powder Rivers, spring runoff is often between mid-January and late March.

The Tongue and Powder Rivers are both perennial streams that originate in the high mountains of Wyoming and drain north to the study area, and then to the Yellowstone River. The Tongue River has an average annual flow of 320,200 acre-feet, and the Powder River, 450,600 acre-feet. Respectively, the two streams account for 3.4 percent and 4.9 percent of the Yellowstone River water at their confluence. The larger tributaries entering the Tongue River within the study area are Hanging Woman Creek, Otter Creek, and Pumpkin Creek. The

Little Powder River and Mizpah Creek are major tributaries to the Powder River.

Climate

The climate is continental, and is characterized by large diel changes in temperature, abundant sunshine, low relative humidity, moderate wind, and pronounced extremes in temperature. Summers are warm with an average annual July temperature of 73°F. Cool nights moderate the warm days. January is the coldest month of the year, averaging 20°F. Cold waves often bring the temperature well below zero but are short in duration and generally are broken by warm pleasant weather.

Spring and early summer are the wettest seasons, when more than half the annual precipitation is received. The mean annual precipitation varies from 12 to 16 inches. The annual snowfall ranges from 35 to 50 inches; however, great depths of snow seldom accumulate, owing to early thaws and wind. The early thaws cause many intermittent streams to flow.

Geology and water-bearing characteristics

The study area is part of a large structural basin that is characterized by relatively recent stream erosion of almost horizontal strata of sandstone, siltstone, and shale with intermixed coal beds. Hills consist of mesa uplands preserved by more resistant sandstone. Also resistant clinker--rock fused by natural combustion of coal--is a prominent feature in the uplands. The valleys contain alluvium which is several feet to more than 100 feet thick.

The geologic formations of significance to surface-water quantity and quality are those that crop out in the study area and are transected by the streams. They are the Hell Creek Formation of Cretaceous age, the Fort Union Formation of Tertiary age, and alluvium of Holocene age. The Fort Union Formation, which is composed of the basal Tullock Member, the intervening Lebo Shale Member, and the overlying Tongue River Member, is by far the most conspicuous.

The Hell Creek Formation is as much as 850 feet thick and is exposed in the mid-Powder River, lower Sarpy Creek, and lower Armells Creek drainages (fig. 1). It consists principally of shale and siltstone; locally, however, fine- to medium-grained sandstone containing thin coal beds predominates (Lewis and Roberts, 1977). Only the basal Hell Creek is important as an aquifer; wells tapping this aquifer yield water ranging in dissolved-solids concentration from 500 to 1,500 mg/L (milligrams per liter) according to R. W. Lee (oral commun., 1977).

The Fort Union Formation is characterized by heterogeneous lithology, truncation of units, and the local absence of some strata. The Tullock Member is generally exposed in the northern part of the study area. It consists of interbedded shale, siltstone, and sandstone; fine-grained sandstone and thin coal beds contain small quantities of sodium-rich water. The Lebo Shale Member, which is somewhat more exposed than the Tullock Member, is limited as an aquifer, generally containing small quantities of water from sandstone units within the shale. The uppermost Tongue River Member is exposed in most of the study area. With its massive sandstone, coal, and clinker beds this member is the major aquifer in much of the study area (Lewis and Roberts, 1977). R. W. Lee (oral commun., 1977) has found dissolved-solids concentrations in water from the Tongue River Member to range from 350 to 4,500 mg/L.

Alluvium, present beneath the valleys, is composed of mixed gravel, sand, silt, and clay. It forms the channel of most reaches of all streams and is a local aquifer. Generally, where the relationship can be determined, the alluvium contributes water and sustains or prolongs flows in most stream channels between periods of precipitation and snowmelt. At times of high streamflow, however, and continuously throughout some stream reaches, water is lost from the channel to the alluvium.

Soils

Soils in the area are derived from poorly consolidated sandstones, siltstones, and shales, mostly of the Fort Union Formation; soil type ranges from sandy to clay loam. In the broadest classification, soils of the area can be divided into residual, alluvial, or a combination of the two.

Residual soils reflect the character of the parent rock both in physical and chemical nature. They generally occur in upland areas such as slopes and ridges. Sandstones often weather to sandy loams that are moderate to nonsaline. Siltstones and shale, in contrast, weather to form silty-clay soils that are often saline and contain sodium as a dominant ion. Runoff from residual soils is generally rapid, producing high to severe erosion conditions.

Alluvial soils are found on terrace deposits, on alluvial fans, or as a covering to valley flood plains. Although the parent material is the same as for residual soils, fluvial transport and size sorting cause a heterogeneous mixture that reflects a variety of sources. The alluvial soils generally are less saline and more permeable than residual soils. They often reside in areas of gentle slope and have a moderate erosion hazard.

Combinations of residual and alluvial soils may create a variety of conditions with respect to permeability, salinity, and erosion hazard.

PROPERTIES MEASURED

Hydrology is the study of water in all its phases--physical, chemical, and biological. In the study reported here, physical and chemical hydrologic properties are emphasized. This section includes a discussion of each group of properties as an aid to the reader in understanding the discussion that follows on water quality for each drainage basin.

Physical properties

Physical measurements include water discharge, suspended sediment, and water temperature.

Measurement of water discharge provides information on the volume of water passing a point per unit time as well as changes in this volume. Some stream reaches may, for example, gain in volume from tributary and ground-water inflow, whereas flow in other stream reaches may be reduced because of infiltration and recharge to the ground-water system. Water discharge also is a controlling factor for the concentration of many chemical compounds and elements. The concentration of the compounds is inversely proportional to the water-discharge volume. Depending upon volume and velocity as well as other factors, water discharge results in the transport of suspended inorganic and organic sediment, bottom material, and organisms.

Suspended sediment is solid material, both mineral and organic, that is in suspension. In flowing water, suspended sediment is maintained in suspension by the upward flow components of turbulent currents or by colloidal suspension. Suspended sediment is of obvious economic importance from the standpoint of the filling of reservoirs and stream reaches (channel filling or deposition). But suspended sediment also plays other important roles in the aquatic environment. Many inorganic elements and compounds such as trace metals are absorbed and adsorbed (sorbed) onto sediment particles. Thus, suspended sediment becomes an important transporting mechanism for these materials in the aquatic environment. Finally, the amount of suspended sediment transported and deposited may have a great influence on the well-being of aquatic life in streams and impoundments.

Water temperature controls the bacterial oxidation rate of organic matter, the growth and production rate of organisms, and to some extent the suspension of sediment in water. Temperature also may be a lethal factor in the environment. All organisms have a definite temperature range within which they can survive. Beyond this range death occurs. However, thermal distress of the organism will take place before the lethal temperature is reached; thus, water temperature also is considered to be a sublethal factor.

Chemical properties

A variety of chemical measurements were made as a part of this study. Many of the measurements are conveniently divided into the categories of major ions or major dissolved constituents, plant nutrients, and trace elements. These categories will be used in describing most of the chemical measurements. Additional measurements that do not fit these categories are biochemical oxygen demand and the in situ measurements of specific conductance, pH, and dissolved oxygen.

The water of a stream consists of a base-flow component composed of ground water that discharges into the stream and a direct-runoff component that enters the drainage system following precipitation and snowmelt. At various times of the year either or both of these components may dominate the character of the stream. Water from the ground-water component has had a long residence time in consolidated and unconsolidated material beneath the land surface. Its dissolved-solids concentration may be relatively high; however, streamflow volume due to base flow only is relatively small. Conversely, the direct runoff presumably has no residence time in the ground and only a short contact with soil and vegetation. Thus, the dissolved-solids concentration of the runoff component is considerably higher than that of the direct precipitation, but much less than it would be during base-flow conditions. Generally, the concentration of dissolved chemical constituents in a stream is inversely related to streamflow.

By convention the major ions or dissolved constituents consist of the cations (positively charged ions) calcium, magnesium, sodium, and potassium, and the anions (negatively charged ions) bicarbonate (or carbonate if the pH is 8.3 or higher), chloride, and sulfate. Silica (SiO_2) also is included in the major-ion-constituent category, even though silica is non-ionic at the pH of most natural waters (6.0 to 8.5). Fluoride and nitrate are sometimes found in high enough concentrations to be considered major ions.

The composition of water is complex with respect to major ions, however, ion sources can be traced to area lithology, soils, and the atmosphere. The major ions are often derived directly from solution of minerals in the rocks and soil. However, some of the anions may be derived in a large part from non-lithologic sources. Bicarbonate present in most water is from the air and is liberated in the soil through biochemical activity. Some rocks and soils serve as sources of chloride and sulfate through direct solution, although circulation of sulfur may be influenced greatly by biologically mediated oxidation and reduction.

The term "dissolved" has been used throughout this discussion. From a physical sense, dissolved refers to particles of very small diameter, but there is no definite diameter size for the dissolved state for each constituent. From a practical standpoint, the term "dissolved" as used above refers (except for dissolved gases) to constituents analyzed in water that have passed through a filter having pores 0.45 micrometer in diameter.

The plant-nutrient category includes most of the above major ions, and most of the trace elements to be discussed later. Through popular usage, the several forms of nitrogen and phosphorus are often regarded as major plant nutrients. Actually the term "major" is a misnomer and should be replaced with the term "limiting." That is, nitrogen and phosphorus (especially phosphorus) are the plant nutrients that are likely to be removed from the water by plants during periods of high plant-production. This activity thus limits further plant production until more of these constituents become available, either from direct addition by man or by plant die-off and subsequent release of nitrogen and phosphorus to the water.

Nitrogen may occur as ammonia, nitrite, nitrate, and as organic nitrogen, which consists of nitrogen bonded to carbon molecules. Usually the highly oxidized nitrate form is considered to be that which is most readily available to algae. But this is not always true and depends upon the type of algae. The form that phosphorus takes in natural water is somewhat uncertain, but the most probable species appears to be the phosphate ion, complexes with metal ions, and colloidal particulate material. Phosphorus and its compounds generally occur in small concentrations in water and thus are more likely to be limiting than nitrogen. Moreover, phosphorus cannot be replenished by the atmosphere as can nitrogen.

Trace elements measured during this study include aluminum, arsenic, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, vanadium, and zinc. These constituents are called trace elements because they generally occur in water in concentrations of micrograms rather than milligrams. Many of these trace elements can specifically be referred to as trace metals, a title that has unfortunately been erroneously expanded to "toxic trace metals." Although all the above constituents can be toxic at high concentrations, they also are essential to life at low concentrations. Thus, the term "toxic" must always be supported by the concentration of the constituent.

Many trace elements are highly insoluble in water and sorb strongly to inorganic and organic sediments. Consequently, the concentration reported from a filtered or so-called in-solution sample may be but a fraction of the concentration found sorbed to solid materials. For this reason, both total (samples analyzed from a sediment-water mixture) and dissolved analyses are reported.

The BOD refers to the biochemical oxygen demand of the water. The BOD analysis is a test concerned with the utilization of dissolved oxygen by bacteria. The BOD refers to the amount of oxygen used by bacteria in oxidizing organic material during a period of 5 days.

Specific conductance, which is a measurement of the ability of water to carry an electrical current, is a measurement for determining the concentration of the major ions in solution.

The pH of water is a measurement of the hydrogen-ion concentration or, more specifically, the hydrogen-ion activity. It is most conveniently expressed in logarithmic units, and represents the negative base-10 log of the hydrogen-ion activity in moles per liter.

Dissolved oxygen is a life-essential gas and thus an important constituent of water. It was measured as part of the study and reported as a percentage of the saturated value at the time of sample collection.

CLASSIFICATION STANDARDS

Many standards and schemes of classification have been devised as a means to discuss water quality and to determine the suitability of water for various uses. This section lists some tables and standards to which reference has been made in this report.

A common, though not precise, way to identify water is on the basis of predominant cation and anion, such as calcium sulfate or sodium bicarbonate (Hem, 1970). Identification of the chemical type of water requires that the analytical results be expressed in comparable units. Concentration in milligrams per liter is multiplied by the particular factor in the table below to convert into milliequivalents per liter, thus making unit concentrations of all ions chemically equivalent.

Cation:	Conversion factor
Sodium	0.04350
Potassium	.02557
Calcium	.04990
Magnesium	.08226
Anion:	
Chloride	.02821
Sulfate	.02082
Bicarbonate	.01639
Carbonate	.03333

References are made throughout the text to drinking water standards. They refer to the recommended drinking water standards of the U.S. Public Health Service (1962) that were in effect during the period of study.

According to the 1962 standards, the following substances should not be present in amounts greater than those shown:

Substance	Concentration, in milligrams per liter
Arsenic (As)	0.05
Cadmium (Cd)	.01
Chromium (hexavelent, as Cr)	.05
Lead (Pb)	.05
Selenium (Se)	.01

An excessive concentration of any of these constituents constitutes a basis for rejection of the drinking water supply (U.S. Public Health Service, 1962). If the water is acceptable on the basis of this set of standards, a second set is considered. These are to be complied with unless no better supply is available.

Substance	Concentration, in milligrams per liter
Chloride (Cl)	250
Copper (Cu)	1
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500
Zinc (Zn)	5

Livestock raising is a major industry throughout the area and stock consumption an important water use. McKee and Wolf (1971) list the upper limits of dissolved-solids concentration for various types of stock as follows:

Livestock	Concentration, in milligrams per liter
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

Some investigators suggest that these values are much too high for optimizing growth and development of livestock. It has also been determined that certain major ions may be more limiting than the sum of all constituents. For example, stock can tolerate the highest dissolved solids when the water is a sodium chloride type.

Based on sodium adsorption (sodium hazard) and conductivity (salinity hazard), a diagram published by the U.S. Salinity Laboratory Staff (1954) is widely used for evaluating irrigation waters (fig. 2). The diagram is divided into 16 areas that are used to rate the degree to which a particular water may create salinity problems and undesirable ion-exchange effects on irrigated land. However, soil conditions, as well as irrigation methods, are not considered and certainly account for some variability in the classification.

All waters within the basin have been classified by the Montana Department of Health and Environmental Sciences in accordance with the statewide scheme "to establish maximum allowable changes in water quality and established limits for pollutants which affect prescribed beneficial uses of state waters." Detailed criteria for streams within the study area can be found in the middle Yellowstone basin plan (Karp and Botz, 1975) and the lower Yellowstone basin plan (Karp and others, 1975).

QUALITY OF THE WATER

Water-quality information for 35 sampling stations follows. The stations are grouped by drainage basins; each drainage has a short introduction, a discussion of station data, and an areal-correlation discussion of data pertaining to the entire drainage. The drainage and stations are listed in downstream order, except where noted in the discussion.

The discussion for each station is accompanied by a listing that summarizes values for the properties, a graph of major-ion relationships for selected samples, and a graph showing the water discharge-suspended

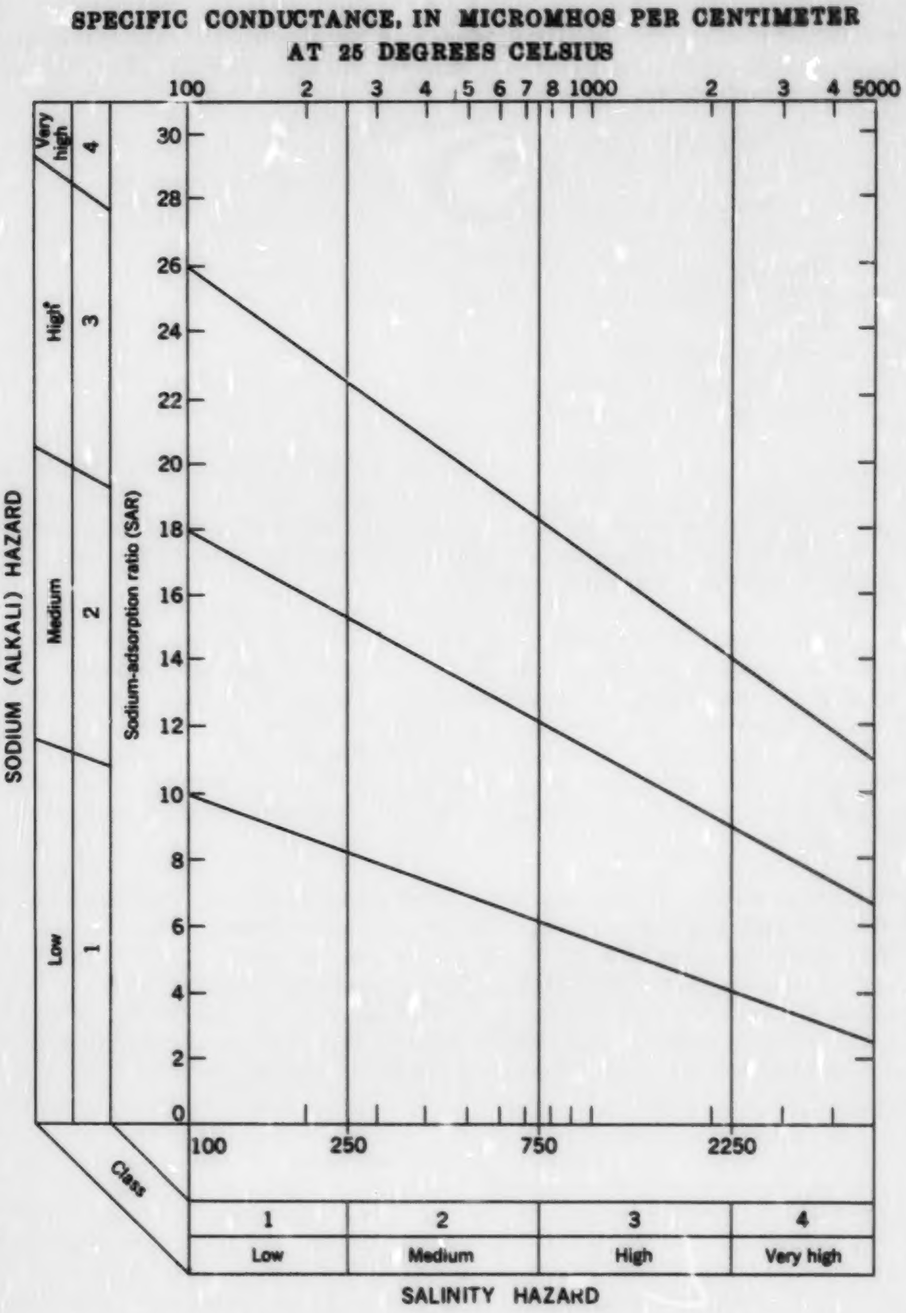


Figure 2.--Classification of water for irrigation.

sediment load relationship (or where less than six samples were collected a listing of sediment results). In the listing of values of the properties, the heading "No. of Analyses" refers to the number of times the constituent was analyzed. The "Mean" is a time-weighted mean in which all samples were given equal emphasis. A discharge-weighted mean is sometimes of more benefit and is often used when samples are collected more frequently (daily). Constituent values listed in the table under "Range" such as discharge, suspended sediment, and specific conductance pertain only to those measurements made during sampling even though continuous record or once-daily measurements are available for some stations. Each major-ion graph depicts samples of the highest, lowest, and mid-range of dissolved-solids concentration. To enable a comparison of major ions for the entire study area at near base-flow conditions, the October 1975 sample (if flow occurred) is one of the three samples. In this graph, as in other illustrations, some of the closely related ions (such as Na+K) are grouped together--the first designated ion of the group is generally dominant. The discharge-sediment graph is a plot of instantaneous suspended-sediment load versus water discharge at the time of sampling. It is often constructed and used to predict sediment loads when only discharge is known. However, on most streams acquisition of more data points is desirable to establish usable relationships between water discharge and suspended sediment.

At sites where streamflow stations were operated during the 1975 water year (Oct. 1974-Sept. 1975) in combination with water-quality stations (fig. 1), a streamflow hydrograph is presented. Three of these stations were also daily suspended-sediment stations; therefore, sediment concentration is also shown on the streamflow hydrograph.

The areal-correlation section of each drainage basin contains illustrations showing the relationship of both major ions and suspended sediment between stations for selected periods. As in other illustrations the major ions are sometimes grouped. The vertical extent between the boundaries of the ions or ion groups represents their concentration in milliequivalents per liter. The Powder River basin suspended-sediment graph (because of daily stations) shows annual suspended-sediment discharges for water years 1975-76. The other sediment graphs compare instantaneous suspended-sediment concentrations between stations. For these, attempts were made to choose static sediment periods. However, the reader should be mindful that sediment transport is variable and the graphs give only a generalized comparison between stations.

Sarpy Creek basin

Sarpy Creek originates in the Little Wolf Mountains and has major tributaries of East Fork Sarpy Creek, Spring Creek, Beaver Creek, Bear Creek, and West Bear Creek (fig. 1). Streamflow in the 453 mi^2 drainage area generally is intermittent. Sarpy Creek flows northward to the Yellowstone River across southeast-dipping strata, exposing the Fort Union Formation south of Beaver Creek and the Hell Creek Formation between Beaver Creek and Bear Creek. The Bearpaw Shale of Late Cretaceous age, which is present in the lower reaches, has little influence on either the water quantity or quality.

The streambeds of Sarpy Creek and its tributaries are generally composed of alluvium into which runoff infiltrates before reaching the main stem. Some water discharges from bedrock aquifers to Sarpy Creek and its tributaries (Van Voast and Hedges, 1974).

Land use in the drainage basin is predominantly agricultural, with cattle and sheep grazing utilizing most of the land. About 870 acres of land is irrigated along Sarpy Creek and its tributaries, with alfalfa and sugar beets being the major irrigated crops. Coal development in upper reaches of the drainage began in 1972. Actual surface mining started in the spring of 1974. A railroad spur that was built to service the mine runs the length of the valley, about 36 miles. Coal production from the Sarpy Creek basin in 1975 totalled 7 million tons and in 1982 is projected to reach twice that amount (U.S. Geological Survey, 1976).

Continuous streamflow at the sampling station Sarpy Creek near Hysham (station 1, fig. 1) has been measured since September 1973. Average mean daily discharges for the 1974 and 1975 water years were 2.77 ft^3/s and 20.1 ft^3/s, respectively, with both years showing many days of no flow during late summer and early fall. Differences in flow reflect the nature of precipitation and temperature patterns for the 2 years. The 1975-water-year hydrograph (fig. 3) shows a flow pattern typical of prairie streams in which runoff occurs in early spring with occasional winter storms or snowmelt.

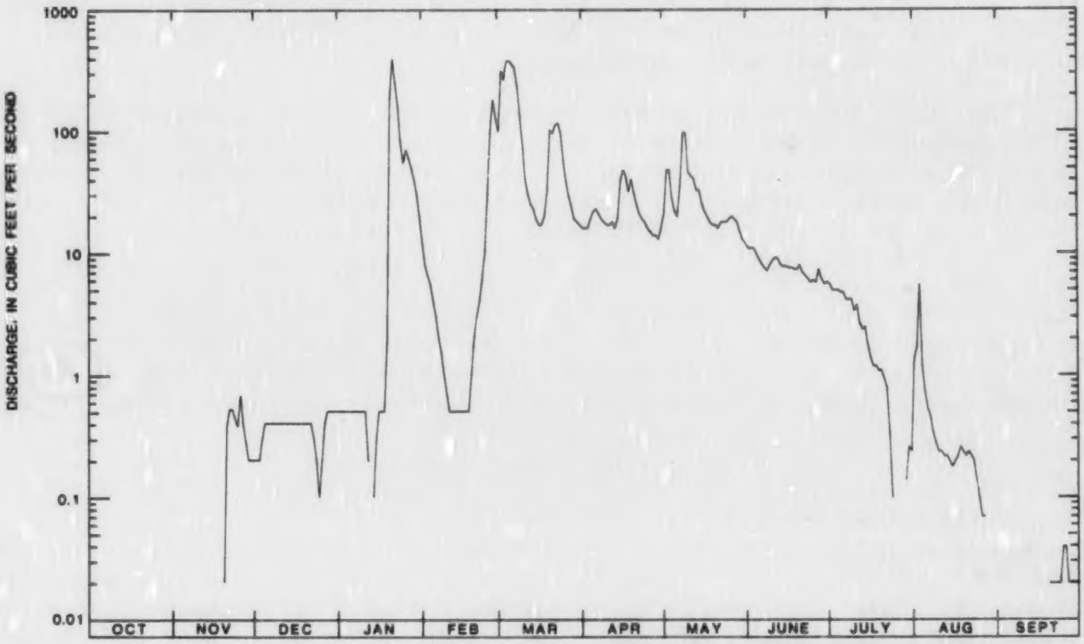


Figure 3.--Hydrograph of stream discharge for Sarpy Creek near Hysham, 1975 water year. Breaks in line continuity represent periods of no flow.

Although this water-quality study was begun in October 1974, no-flow conditions prevailed during October and most of November of that year. During water years 1975 and 1976 sampling was done monthly when flow conditions existed. As would be expected, concentrations of major dissolved constituents varied inversely with streamflow, which is illustrated by the major-ion graph of figure 4. Conversely, concentrations of total constituents analyzed from the water-sediment mixture often varied directly with streamflow.

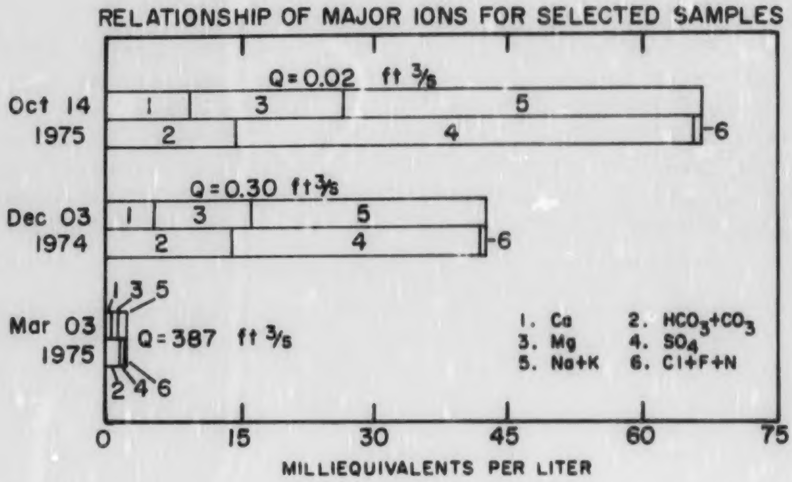
Except during periods of major runoff the chemical character of the water was a sodium sulfate type having a relatively high concentration of dissolved solids. Dissolved-solids concentrations exceeded the recommended limit of 500 mg/L for drinking water, but were generally lower than the upper limits for stock water. The sodium hazard for irrigation water ranged from low to medium and the salinity hazard was high (see fig. 2). Water in Sarpy Creek is suitable for use by salt-tolerant crops such as alfalfa but would be restrictive to many crops. Boron was present in amounts sufficient for plant requirements, but not in quantities that are considered to be toxic. Nutrients of the nitrogen and phosphorus family, analyzed from the water-sediment mixture, were highest at times of snowmelt and storms.

Discharges greater than 20 ft^3/s were measured twice during the sampling period. These occurred on January 19 and March 3, 1975, with measured discharges of 193 and 411 ft^3/s, respectively. The chemical character of the water changed, with sodium and bicarbonate becoming the dominant cation and anion and the dissolved-solids concentration decreasing to values of less than 200 mg/L. Analyses of samples from the water-sediment mixture collected during these periods of runoff had high values for both BOD and nutrients of the nitrogen and phosphorus families. Runoff undoubtedly flushed organic debris and stock feces from surface areas into the stream. The January 19 sample included a moderately high value for total iron of 11,000 µg/L (micrograms per liter).

Suspended sediment exhibited a direct relationship to water discharge as illustrated in the sediment-discharge graph (fig. 4). The scatter of the plotted data, which can be attributed to sediment availability, is typical of many smaller streams. Drainage conditions such as frozen ground, channel flushing, stock-pond impoundments, and irrigation practices have much influence on sediment availability. The maximum measured concentrations at this station were rather low when compared to sediment data from streams farther east in the study area.

Armells Creek basin

Armells Creek drains an area of about 370 mi^2. The major tributaries are East Fork and West Fork, which originate along the eastern flank of the Little Wolf Mountains and drain the west side of Armells Creek valley (fig. 1). Both forks occupy wide, well-developed valleys similar in appearance to the lower valley. Above their confluence, the channels of both


RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES

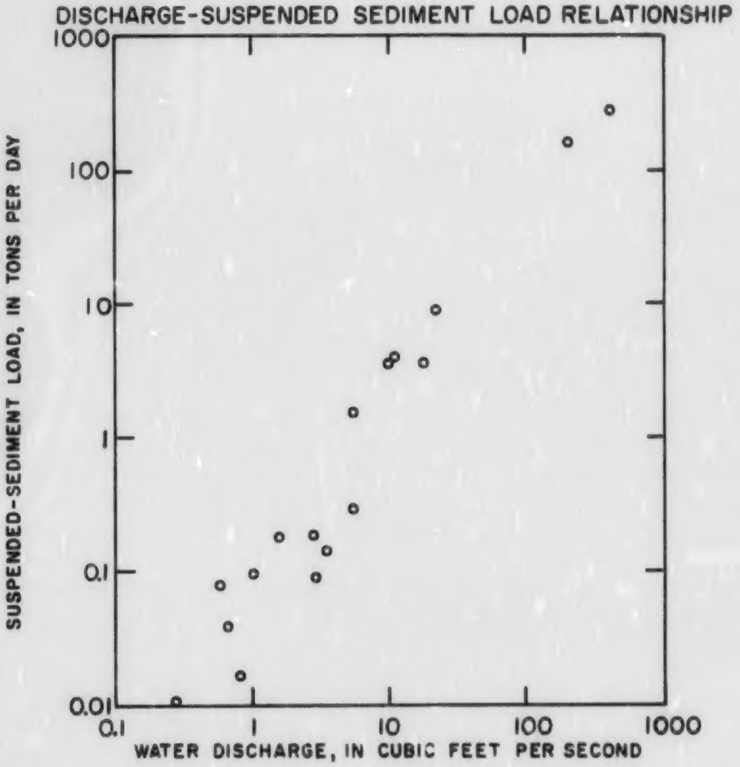

DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 4.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Sarpy Creek near Hysham (station 1).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	20		0.02-411	ft^3/s
Specific conductance (at 25 deg. C)	20	2510	215-4300	umhos/cm
pH	20	8.2	7.6-8.5	units
Temperature	20	7.0	0.0-23.0	deg. C
Turbidity	20	20	3-100	JTU
Dissolved oxygen	20	80	16-108	percent
Biochemical oxygen demand	19	2.6	.0-12.0	mg/L
Calcium (Ca), dissolved	20	90	18-190	mg/L
Magnesium (Mg), dissolved	20	110	8.0-210	mg/L
Sodium (Na), dissolved	20	375	14-880	mg/L
Percent sodium	20	52	23-65	percent
Sodium-adsorption ratio	20	6.1	.6-10	---
Potassium (K), dissolved	20	9.9	7.2-14	mg/L
Bicarbonate (HCO_3)	20	545	89-886	mg/L
Carbonate (CO_3)	20	4.0	0-30	mg/L
Sulfate (SO_4), dissolved	20	993	40-2500	mg/L
Chloride (Cl), dissolved	20	14	3.1-33	mg/L
Fluoride (F), dissolved	20	.3	.1-.5	mg/L
Silica (SiO_2), dissolved	20	7.2	.5-12	mg/L
Dissolved solids (calculated)	20	1870	150-4280	mg/L
Nitrite plus nitrate, total as N	20	.07	.00-.46	mg/L
Nitrogen, ammonia, total as N	20	.06	.01-.34	mg/L
Nitrogen, total organic as N	20	.82	.40-2.5	mg/L
Nitrogen, total kjeldahl as N	20	.88	.42-2.7	mg/L
Phosphorus, total as P	20	.08	.00-.46	mg/L
Suspended sediment	20	78	6-280	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-10	6	110-1500	ug/L
Arsenic	2	1-2	10	0-11	ug/L
Beryllium	2	0-<10	10	0-10	ug/L
Boron	20	110-680	---	---	ug/L
Cadmium	2	0-1	10	0-20	ug/L
Chromium	2	0-<10	10	0-20	ug/L
Copper	2	1-3	10	<10-90	ug/L
Iron	20	10-410	10	140-11000	ug/L
Lead	2	1-3	10	<100-100	ug/L
Lithium	2	40-80	10	10-70	ug/L
Manganese	2	50-130	10	20-6000	ug/L
Mercury	2	.0-<.1	10	.0-.1	ug/L
Molybdenum	2	2-<5	10	1-6	ug/L
Nickel	2	1-5	10	0-100	ug/L
Selenium	1	0	10	0-1	ug/L
Vanadium	2	1.9-<8.0	---	---	ug/L
Zinc	2	10	6	8-120	ug/L

Figure 4.--Continued.

forks transect sections of the Fort Union Formation; below the confluence the lower valley floor is the Hell Creek Formation. As much as 40 feet of alluvium underlies the valley of the East Fork (Van Voast and Hedges, 1975).

Livestock raising has been an important agricultural industry since the area was settled, and stock watering is the major use of the creek. During periods of high flow, some flood irrigation is practiced along stream channels.

Coal mining was initiated in 1924 near the town of Colstrip by Northwest Improvement Co., a subsidiary of the Northern Pacific Railway Co. The major mines operated near Colstrip are serviced by a railroad line from Forsyth on the Yellowstone River (fig. 1).

Sampling stations are located on the East Fork about 7 miles north of Colstrip (station 2), on the West Fork near its confluence with the East Fork (station 3), and near the mouth of Armells Creek near Forsyth (station 4) about 2 miles upstream from the Yellowstone River (fig. 1). Armells Creek near Forsyth is a continuous-recording streamflow station that has been in operation since July 1974.

East Fork Armells Creek near Colstrip

The sampling site East Fork Armells Creek near Colstrip is near the midpoint of the East Fork drainage. The stream channel at the sampling site is entrenched only slightly and high flows spread out onto the flood plain. A low gradient causes pooling and stagnation--favorable for the abundant growth of aquatic vegetation. These conditions are typical of the East Fork downstream from Colstrip. Samples were collected only at times of visible flow between pools, although downgradient subsurface movement presumably occurs at times of no visible flow. Except for no-flow conditions during extreme cold and during hot dry summer periods, streamflow generally ranged from 1 to 5 ft^3/s. The only flows greater than 10 ft^3/s that were sampled were 169 ft^3/s on January 20, 1975, and 21 ft^3/s on March 4, 1975.

At flows of less than 10 ft^3/s the dominant cation and anion found in the water were magnesium and sulfate, respectively (fig. 5). The chemical character of the water reflects the influence of the Tongue River Member of the Fort Union Formation, which is conspicuous in the drainage upstream from the station.

For flows of less than 10 ft^3/s, dissolved-solids concentrations commonly ranged from 3,000 to 4,000 mg/L. Little correlation was noticed between concentrations and streamflow; the variations that existed may have been influenced by such factors as evaporation, transpiration, and icing.

Samples collected during periods of high runoff in January and March 1975 showed significant reduction in dissolved-solids concentration and a change in the relative proportion of the major ions. Both calcium and bicarbonate made up greater percentages of cations and anions (fig. 5). The overland runoff accumulated organic debris, resulting in high values for total phosphorus and

BOD. Concentrations of some total metals, especially iron, were the highest of record for this site during the January sampling. However, the values were within the range of those for other stations in the area.

Some forms of nitrogen had higher concentrations than were found in similar streams elsewhere in the study area. The higher values, especially those for ammonia, may indicate the influence of upstream contributions of waste effluent. Nitrogen doubtless provides nutrients for the dense aquatic vegetative growth in the channel and is a factor sustaining it.

The water appears to be suitable for stock use although values of sulfate are sometimes high according to limits of McKee and Wolf (1971). Only during the runoff periods when dissolved-solids concentrations are greatly reduced would water be suitable for irrigation.

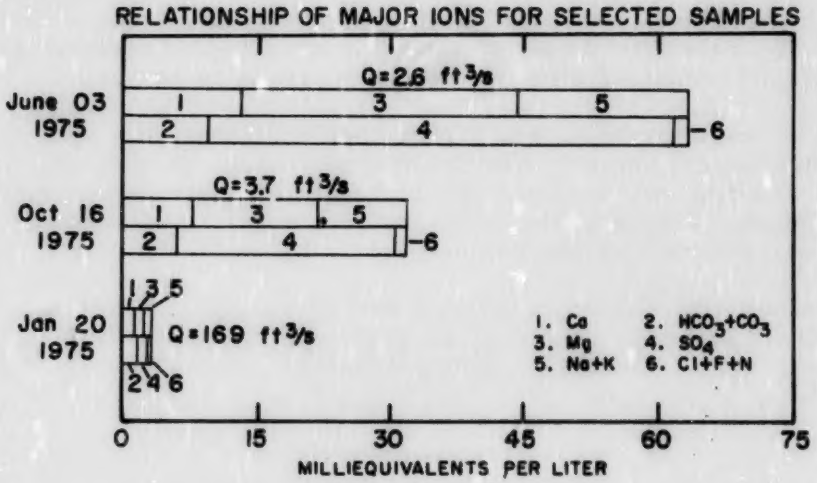
Suspended-sediment concentrations throughout all flow conditions were generally lower than for most other streams of similar size. This may be the result of the pool-and-riffle nature of the stream and frozen ground conditions during some runoff periods. Dense aquatic plant growth also provides channel stability and reduces bank erosion. The highest flow sampled, which was on January 20, 1975, had a suspended-sediment concentration of 68 mg/L and a suspended-sediment load of 31 tons/day (fig. 5). Flows of less than 10 ft^3/s sometimes exceeded the above sediment concentration by a factor of 2 to 3. Past mining operations left spoils that show evidence of erosion, but it is doubtful that much of this sediment reached the station during any sampling period.

West Fork Armells Creek near Forsyth

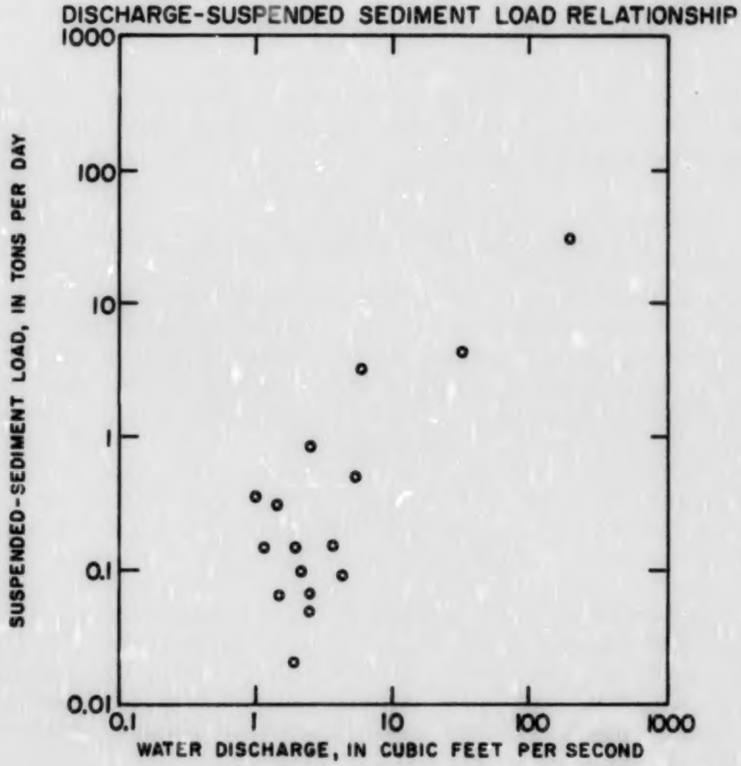
Channel characteristics for the sampling site West Fork Armells Creek near Forsyth are much the same as the station on the East Fork except that channel vegetation is not as abundant. Stock ponds upstream tend to moderate flows, to create some mixing action, and to allow some of the suspended sediment to settle. Like the East Fork, the stream is intermittent and during some visits samples were not taken because no flow was visible between pools. Fifteen of the 20 sampled flows were less than 1 ft^3/s. The highest flow sampled was 28 ft^3/s on March 3, 1975. The station was not sampled during the major runoff in January 1975, but that flow is estimated to have peaked between 100 and 200 ft^3/s.

Water in the West Fork, except for the three highest flows, is classified as a sodium sulfate type (fig. 6) and may reflect the influence of water from the Tullock and Lebo Shale Members of the Fort Union Formation, which form much of the drainage. At higher flows when surface-water runoff was the major contributor, calcium and bicarbonate showed increasing percentages of the total cations and anions, respectively.

Dissolved-solids concentrations ranged from 383 to 5,710 mg/L, with most samples having between 4,000 and 5,000 mg/L. These concentrations are about 40 percent greater than those of the East Fork.



RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 5.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for East Fork Armells Creek near Colstrip (station 2).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	16		1.0-169	ft^3/s
Specific conductance (at 25 deg. C)	16	3290	290-4820	umhos/cm
pH	16	8.1	7.5-8.6	units
Temperature	16	8.5	0-24.5	deg. C
Turbidity	16	10	0-40	JTU
Dissolved oxygen	15	98	67-205	percent
Biochemical oxygen demand	16	2.4	.1-11	mg/L
Calcium (Ca), dissolved	16	200	22-290	mg/L
Magnesium (Mg), dissolved	16	264	13-430	mg/L
Sodium (Na), dissolved	16	303	13-430	mg/L
Percent sodium	16	28	19-33	percent
Sodium-adsorption ratio	16	3.2	.5-4.0	----
Potassium (K), dissolved	16	17	7.4-23	mg/L
Bicarbonate (HCO_3)	16	442	71-621	mg/L
Carbonate (CO_3)	16	0	0	mg/L
Sulfate (SO_4), dissolved	16	1800	75-2600	mg/L
Chloride (Cl), dissolved	16	50	4.1-86	mg/L
Fluoride (F), dissolved	16	.4	.0-.7	mg/L
Silica (SiO_2), dissolved	16	7.8	1.4-17	mg/L
Dissolved solids (calculated)	16	2870	178-4110	mg/L
Nitrite plus nitrate, total as N	16	.16	.00-.88	mg/L
Nitrogen, ammonia, total as N	16	.27	.00-1.1	mg/L
Nitrogen, total organic as N	16	1.3	.39-2.6	mg/L
Nitrogen, total kjeldahl as N	16	1.5	.49-3.1	mg/L
Phosphorus, total as P	16	.08	.00-.33	mg/L
Suspended sediment	16	50	7-180	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-30	6	20-190	ug/L
Arsenic	2	1-2	8	0-5	ug/L
Beryllium	2	0-10	8	0-10	ug/L
Boron	16	120-970	---	---	ug/L
Cadmium	2	0-1	8	10-20	ug/L
Chromium	2	0-2	8	0-30	ug/L
Copper	2	0-16	8	10-40	ug/L
Iron	16	20-160	8	210-2400	ug/L
Lead	2	3-4	8	100-100	ug/L
Lithium	1	100	8	10-130	ug/L
Manganese	2	0-250	8	30-750	ug/L
Mercury	2	0	8	.0-.4	ug/L
Molybdenum	1	2	8	0-3	ug/L
Nickel	2	0-4	8	50-100	ug/L
Selenium	1	0	8	0-1	ug/L
Vanadium	1	1.6	---	---	ug/L
Zinc	2	10-20	6	0-40	ug/L

Figure 5.--Continued.

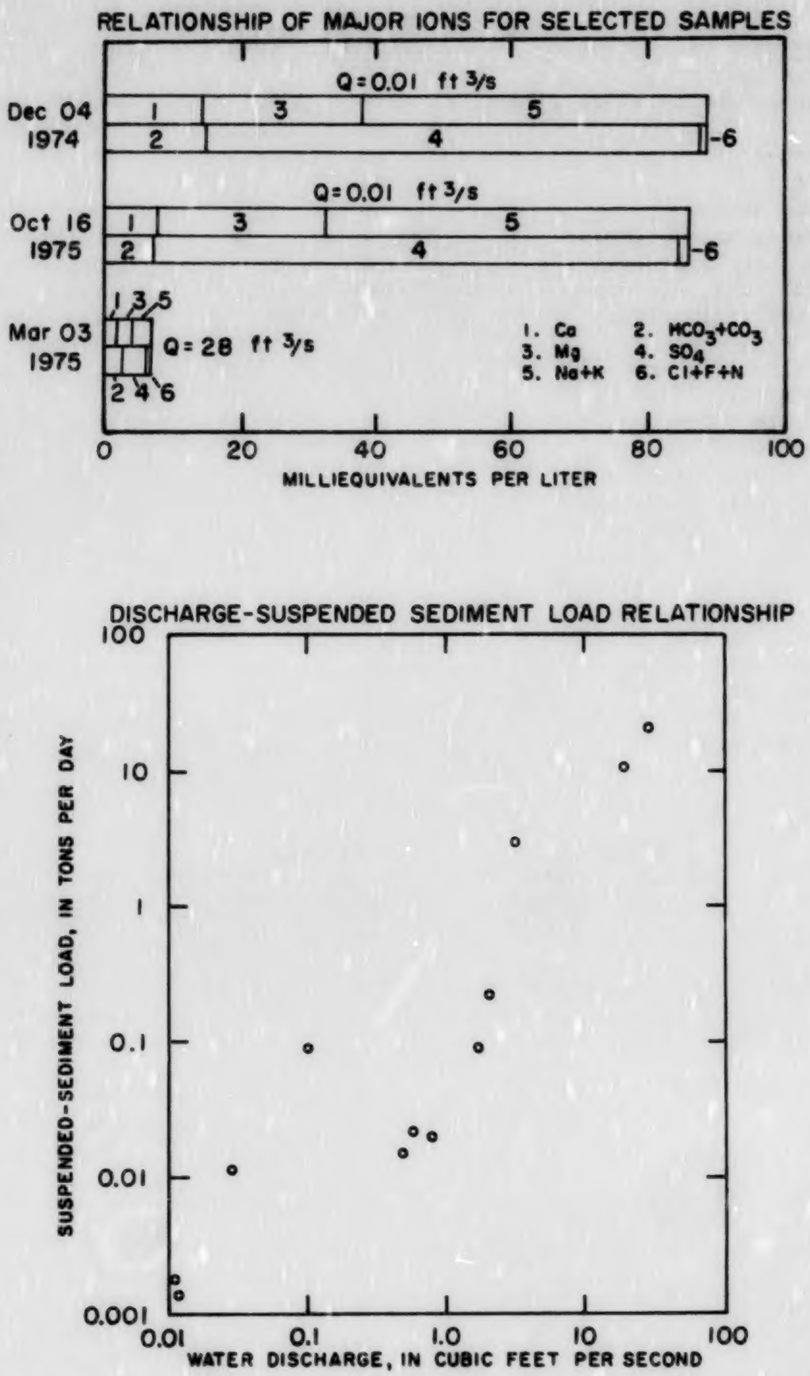


Figure 6.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for West Fork Armells Creek near Forsyth (station 3).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	16		.01-28	ft^3/s
Specific conductance (at 25 deg. C)	16	4920	765-7100	umhos/cm
pH	16	8.0	7.4-8.9	units
Temperature	16	7.0	0.0-22.5	deg. C
Turbidity	16	15	2-100	JTU
Dissolved oxygen	16	85	49-103	percent
Biochemical oxygen demand	16	2.0	.5-8.4	mg/L
Calcium (Ca), dissolved	16	190	33-280	mg/L
Magnesium (Mg), dissolved	16	215	27-290	mg/L
Sodium (Na), dissolved	16	830	57-1200	mg/L
Percent sodium	16	56	38-62	percent
Sodium-adsorption ratio	16	9.5	1.8-13	---
Potassium (K), dissolved	16	13	6.9-16	mg/L
Bicarbonate (HCO_3)	16	557	134-875	mg/L
Carbonate (CO_3)	16	1	0-11	mg/L
Sulfate (SO_4), dissolved	16	2600	180-3800	mg/L
Chloride (Cl), dissolved	16	31	4.3-81	mg/L
Fluoride (F), dissolved	16	.3	.1-.6	mg/L
Silica (SiO_2), dissolved	16	8.3	1.0-19	mg/L
Dissolved solids (calculated)	16	4150	383-5710	mg/L
Nitrite plus nitrate, total as N	16	.04	.00-.33	mg/L
Nitrogen, ammonia, total as N	16	.05	.02-.11	mg/L
Nitrogen, total organic as N	16	1.0	.42-2.4	mg/L
Nitrogen, total kjeldahl as N	16	1.1	.44-2.5	mg/L
Phosphorus, total as P	16	.05	.00-.27	mg/L
Suspended sediment	14	105	9-261	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	10	4	20-300	ug/L
Arsenic	1	1	6	0-2	ug/L
Beryllium	1	10	6	0-10	ug/L
Boron	16	130-710	---	---	ug/L
Cadmium	1	0	6	10-30	ug/L
Chromium	1	10	6	0-20	ug/L
Copper	1	1	6	10-30	ug/L
Iron	16	10-420	6	230-920	ug/L
Lead	1	2	6	0-100	ug/L
Lithium	1	50	6	10-60	ug/L
Manganese	1	40	6	50-800	ug/L
Mercury	1	.1	6	.0-.1	ug/L
Molybdenum	1	2	6	0-1	ug/L
Nickel	1	4	6	0-150	ug/L
Selenium	1	0	6	0-4	ug/L
Vanadium	1	1.7	---	---	ug/L
Zinc	1	20	4	10-40	ug/L

Figure 6.--Continued.

The water would be suitable for irrigation only at times of high runoff. During periods of reduced flow not only would quantity be a restrictive factor, but both the salinity and sodium hazards would be too great. Like the East Fork water, dissolved-solids concentrations are not at a level that would restrict consumption for most stock; however, sulfate concentrations are near values that are considered restrictive (McKee and Wolf, 1971).

Suspended-sediment concentrations generally were less than 50 mg/L. Much of the sediment was trapped in the many upstream stock ponds or natural pools. The highest concentration of suspended sediment was 261 mg/L measured on March 3, 1975. It coincided with the highest measured flow, and represented a calculated suspended-sediment load of 20 tons/day (fig. 6).

Armells Creek near Forsyth

The drainage area above the station Armells Creek near Forsyth is 370 mi^2 of which about 200 acres is irrigated. The stream channel is more defined than the channels of the East and West Forks, and like the two forks shows ponding with riffles between. Vascular plants and other vegetation grow along much of the channel.

Although streamflow was perennial during the 1975 water year (fig. 7),

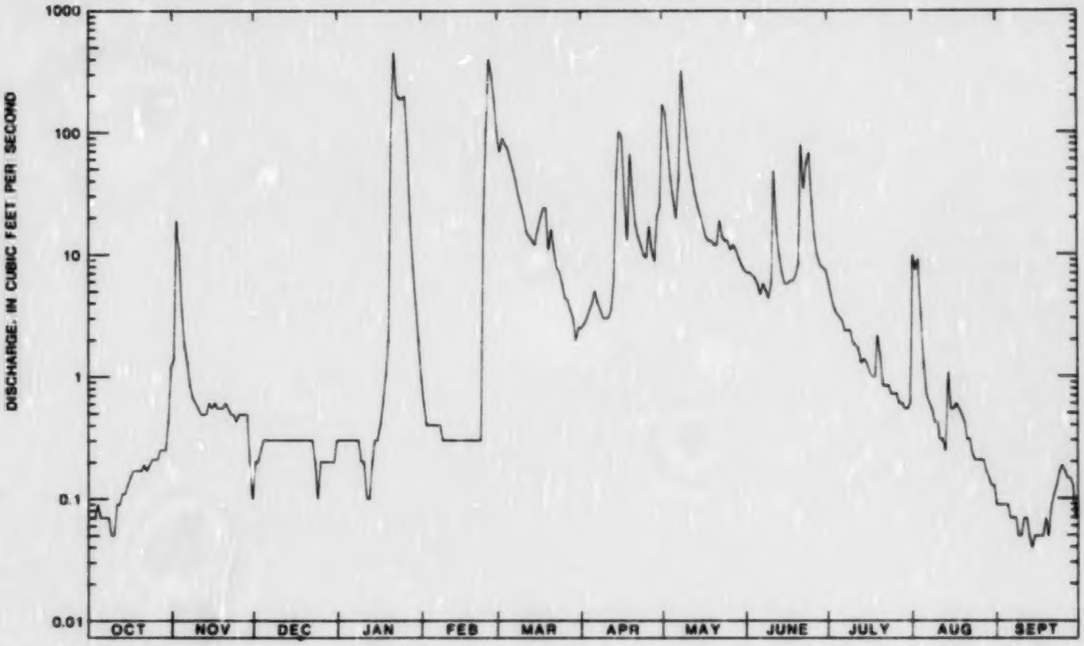


Figure 7.--Hydrograph of stream discharge for Armells Creek near Forsyth, 1975 water year.

more than half the time the mean daily discharges were less than 1 ft^3/s. In the late summer and early fall, discharges recorded less than 0.1 ft^3/s. Peak flows and high flows were coincidental with storms, chinooks, and spring runoff. The highest flow sampled was 462 ft^3/s on January 21, 1975, although 17 of the 25 samples were collected from flows of less than 5 ft^3/s.

Except when influenced by high surface runoff, the water was characteristically a sodium sulfate type (fig. 8) similar to water sampled on the West Fork. This station, like the others on Armells Creek, had chloride concentrations exceeded only by stations on the Powder River.

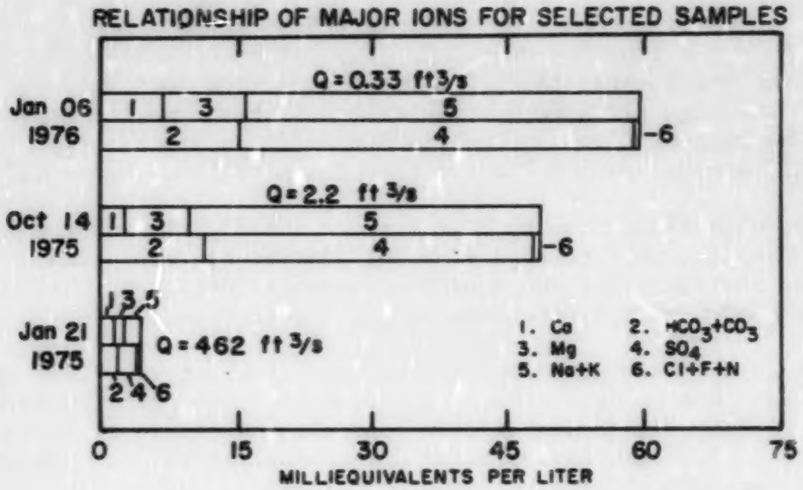
Although the mean dissolved-solids concentration was 2,870 mg/L, 18 of the 25 samples had concentrations in excess of 3,500 mg/L. Concentration variations during low-to-medium flow conditions appeared to be independent of discharge. Increased evaporation and transpiration from pooling may have been partly responsible for the poor correlation.

On three occasions dissolved oxygen exceeded 120 percent of saturation. The lowest measured oxygen depletion was 69 percent of saturation under ice conditions in February 1975. Nitrogen concentrations showed a cyclic pattern with increases in the fall and winter and reductions during the spring and summer. Uptake of nitrogen by aquatic plants during the growing season and release at other periods may be responsible.

Total constituents analyzed from the water-sediment mixture, as expected, often had their highest values during peak flows when sediment concentrations were high. BOD and total phosphorus were measured as 9.9 mg/L and 0.51 mg/L, respectively, during the highest sampled flow in January 1975. At the same time total copper was 300 µg/L and iron was 9,700 µg/L. Conversely, total aluminum had its highest value of 2,200 µg/L during a low flow of 2.2 ft^3/s on October 14, 1975. Measurement of the various dissolved trace elements on two separate samplings showed near-average values when compared to other streams in the area.

Water of Armells Creek would be good for irrigation only when flows consist predominantly of surface runoff. At other times the SAR (sodium-adsorption ratio) values indicate a medium sodium hazard and dissolved-solids concentrations indicate a very high salinity hazard.

During low to medium flows (less than 20 ft^3/s) sediment concentrations never exceeded 300 mg/L. The highest measured concentration was 1,100 mg/L on March 4, 1975, which represented a calculated suspended-sediment load of 229 tons/day. The sample was collected on the recession of a peak flow that passed the station 6 days earlier and was probably much less than the concentration during the peak. The highest sampled flow of 462 ft^3/s had a calculated suspended-sediment load of 714 tons/day (fig. 8), although the suspended-sediment concentration was only 572 mg/L. Frozen ground at the time of the high surface runoff reduced the availability of sediment and decreased the expected concentration.



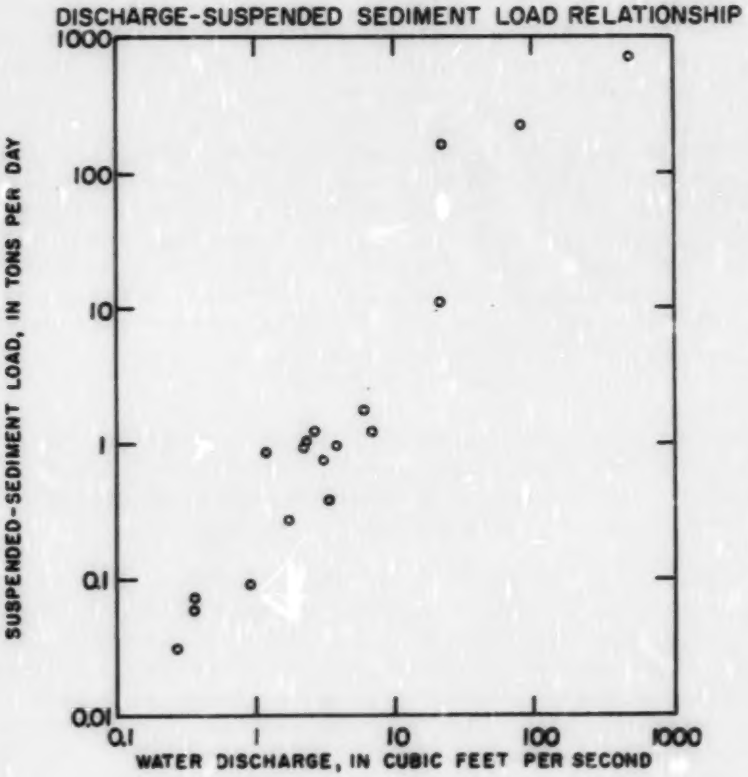


Figure 8.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Armells Creek near Forsyth (station 4).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	25		0.04-462	ft^3/s
Specific conductance (at 25 deg. C)	25	3670	395-6500	umhos/cm
pH	24	8.2	7.4-8.7	units
Temperature	25	9.5	0.0-25.0	deg. C
Turbidity	25	55	1-400	JTU
Dissolved oxygen	25	98	69-138	percent
Biochemical oxygen demand	25	2.5	.0-9.9	mg/L
Calcium (Ca), dissolved	25	111	24-210	mg/L
Magnesium (Mg), dissolved	25	120	12-250	mg/L
Sodium (Na), dissolved	25	640	35-1000	mg/L
Percent sodium	25	62	36-80	percent
Sodium-adsorption ratio	25	10	1.5-18	---
Potassium (K), dissolved	25	10	6.5-12	mg/L
Bicarbonate (HCO_3)	25	523	89-913	mg/L
Carbonate (CO_3)	24	4	0-36	mg/L
Sulfate (SO_4), dissolved	25	1700	110-2700	mg/L
Chloride (Cl), dissolved	25	31	4.7-260	mg/L
Fluoride (F), dissolved	25	.4	.1-.6	mg/L
Silica (SiO_2), dissolved	25	6.2	1.2-14	mg/L
Dissolved solids (calculated)	25	2870	245-4210	mg/L
Nitrite plus nitrate, total as N	25	.06	.00-.23	mg/L
Nitrogen, ammonia, total as N	25	.05	.00-.16	mg/L
Nitrogen, total organic as N	25	.94	.31-2.0	mg/L
Nitrogen, total kjeldahl as N	25	.99	.34-2.1	mg/L
Phosphorus, total as P	25	.10	.01-.51	mg/L
Suspended sediment	24	159	13-1100	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	10	6	210-2200	ug/L
Arsenic	2	1-2	11	0-5	ug/L
Beryllium	2	0-<10	11	0-20	ug/L
Boron	25	140-600	---	---	ug/L
Cadmium	2	0	11	<10-20	ug/L
Chromium	2	<10-10	11	0-64	ug/L
Copper	2	1-3	11	<10-300	ug/L
Iron	25	0-510	11	250-9700	ug/L
Lead	2	0-3	11	<100-100	ug/L
Lithium	2	30-40	11	10-60	ug/L
Manganese	2	60-120	11	30-210	ug/L
Mercury	2	.0-<.1	11	.0-.6	ug/L
Molybdenum	2	2-<6	11	0-5	ug/L
Nickel	2	3-6	11	<50-100	ug/L
Selenium	1	0	11	0-1	ug/L
Vanadium	2	2.3-<8	---	---	ug/L
Zinc	2	<10-20	6	10-40	ug/L

Figure 8.--Continued.

Areal correlation

Concentrations of dissolved and suspended constituents for stations on the East Fork and near the mouth of Armells Creek are shown on figure 9. The West Fork station, which is situated closer to the valley center, contributes flow between the sites.

The major-ion graph (fig. 9A) compares major ion composition of water collected at the two stations 1 day apart in April 1975. Streamflow fluctuated little during this period. The upstream and downstream stations had respective discharges of 2.5 and 2.7 ft^3/s, while the West Fork was contributing 1.5 ft^3/s between the sites. Graphical trends show (1) a downstream change in dominant cation from magnesium to sodium and (2) a downstream reduction in the dissolved-solids concentration.

Changes in dominant ions may be due to inflow of water from the Tullock and Lebo Shale Members of the Fort Union Formation that are transected by the stream between the two stations. The West Fork, which has a drainage formed primarily of the same geologic units, exhibits a water type similar to that of the downstream station.

The downstream decrease in dissolved-solids concentration appears to be from causes other than dilution. Increases in water volume seem to be insufficient for dilution to be responsible. This, of course, could only be verified by a study of the water budget for the stream.

The suspended-sediment graph (fig. 9B) shows that during low- to medium-flow conditions, concentrations are relatively low with little or no increase as the water moves downstream. The gentle gradient and pooling nature of the stream appear to be responsible. At higher flows the pools no longer act as sediment traps and a better direct correlation seems to exist between discharge and suspended-sediment concentration. However, at higher flows, when the ground is frozen, this correlation is modified.

Sediment is derived from a combination of channel erosion and soil erosion from overland runoff. As flow increases the stream width becomes larger, thereby often accelerating bank erosion. Greater water velocities provide increased energy for scouring and transport of sediment. Higher flows often are the result of overland runoff, which furnishes additional sediment to the channel.

Rosebud Creek basin

Rosebud Creek originates a few miles north of the Montana-Wyoming border and drains the eastern flanks of the Wolf and Rosebud Mountains (fig. 1). The uplands (mountains) near the headwaters are tree-covered in contrast to the grasslands of the lower drainage. The descent from the uplands to tributary valleys generally is steep but flattens to irregular dissected slopes that merge with the valley bottoms. The middle and lower valley is broad, grass-covered, and mature with poorly defined divides.

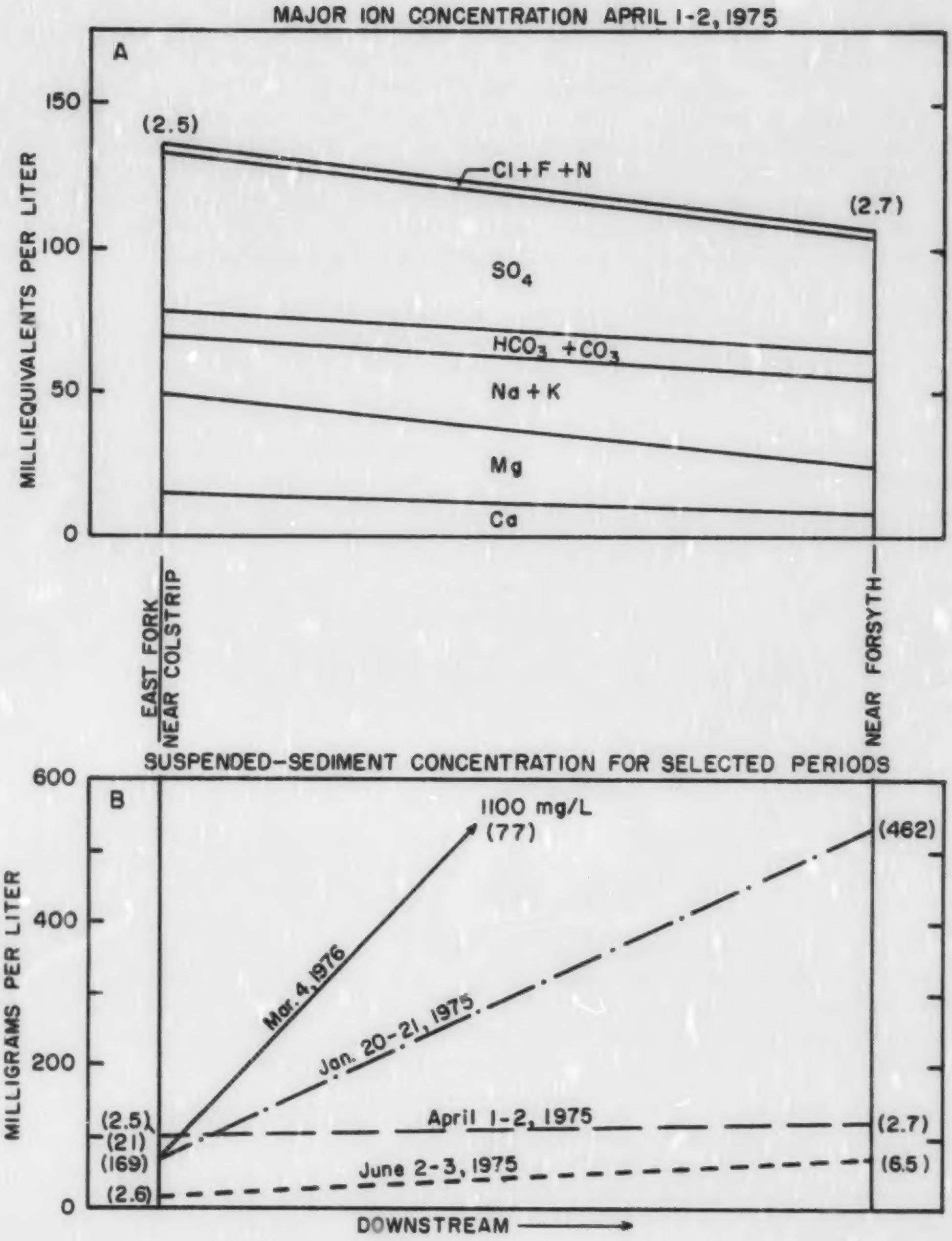


Figure 9.--Concentrations of (A) dissolved constituents and (B) suspended sediment for selected periods on Armells Creek. Numbers in parentheses represent stream discharge at time of sampling, in cubic feet per second.

Valley alluvium generally ranges in width from 300 to 600 feet (Lewis and Roberts, 1977) and has been reported to be as much as 100 feet thick. The alluvium of the upper and middle valley rests on the Tongue River Member of the Fort Union Formation. The lower third of the stream flows downsection across the Lebo Shale and Tullock Members of the Fort Union Formation and finally across the Hell Creek Formation about 25 miles upstream from the mouth. The stream has intermittent flow patterns from the headwaters to near Kirby with most of the tributaries being similar. Lame Deer Creek flows perenially and appears to be the largest contributing tributary.

Agriculture is the major land-use practice in the 1,302 mi^2 drainage basin, with stock grazing predominant. About 2,000 acres is irrigated, mostly for hay and alfalfa in the middle and lower valley. Timber is harvested in parts of the upper drainage.

The four sampling stations on Rosebud Creek and one tributary station are located in the lower valley (fig. 1). About 60 percent of the drainage lies upstream from the uppermost station, Rosebud Creek near Colstrip (station 5). This station and Rosebud Creek at mouth near Rosebud (station 9) are both continuous-recording streamflow stations. Rosebud Creek above Pony Creek near Colstrip (station 7) and Rosebud Creek near Rosebud (station 8) are located about equidistant between the two recording stations. Greenleaf Creek near Colstrip (station 6) is a station on a tributary that enters between the two uppermost Rosebud stations. Samples were collected monthly at the Rosebud Creek stations and during intermittent flows on Greenleaf Creek.

Rosebud Creek near Colstrip

The drainage area upstream from the station Rosebud Creek near Colstrip is 799 mi^2, with about 800 acres of this under irrigation. The channel near the sampling site is slightly meandering and has a stable bottom composed of cobbles and finer material. Grasses, bushes, and trees line the channel and aquatic growth consists mostly of vascular plants and periphyton.

The 1975-water-year hydrograph (fig. 10) shows stable flows throughout the year. Peak flows were moderated at this point in the drainage and the spring runoff exhibited steady rises and declines, with only minor fluctuations. Recorded flows during the 1975 water year ranged from 12 to 402 ft^3/s.

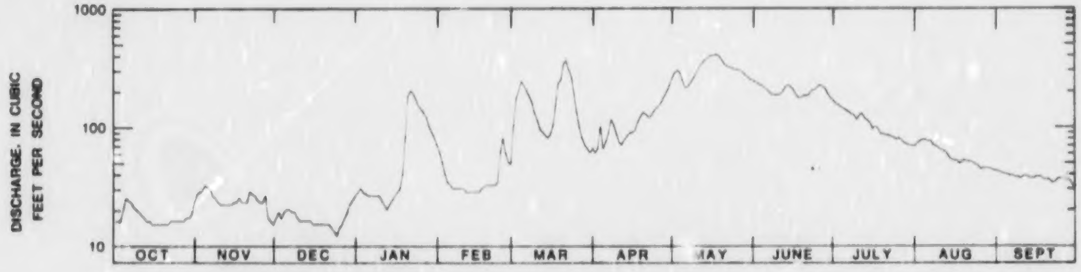


Figure 10.--Hydrograph of stream discharge for Rosebud Creek near Colstrip, 1975 water year.

At flows below 150 ft^3/s the chemical character of the water was dominated by the magnesium cation and the bicarbonate anion (fig. 11). As streamflow approached the higher discharges calcium increased among the cation percentages, magnesium decreased, and sodium changed very little. The anion ratio during higher flows showed slightly greater percentages of bicarbonate and lesser percentages of sulfate. The modification in the chemical character of the water from low to high flow indicates that surface runoff from the upstream drainage is of the calcium bicarbonate type.

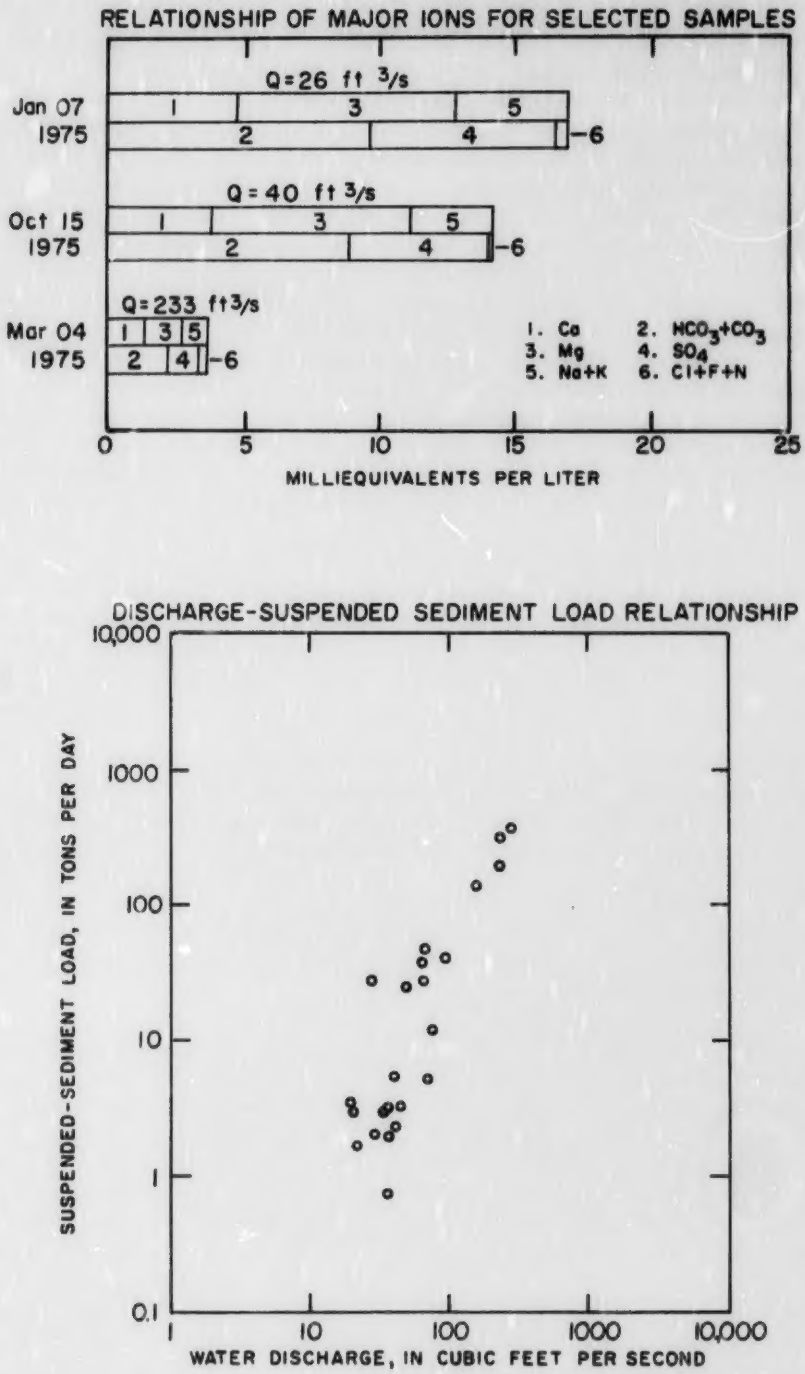
Although the lowest measured concentration for dissolved solids was 198 mg/L, during 80 percent of the sampling the values were between 700 and 900 mg/L. Correlation between dissolved-solids concentration and discharge was generally poor during medium- and low-flow conditions. Irrigation practices, evaporation, transpiration, and icing are at least partly responsible for the poor correlation. The highest dissolved-solids load, calculated from a discharge of 218 ft^3/s and a concentration of 703 mg/L, was 414 tons/day on May 6, 1975. The smallest calculated load was 42.9 tons/day on October 9, 1974.

During much of the year the water had a characteristic yellow-brown color that was probably associated with suspended-sediment fines. Stream aeration was good and dissolved oxygen generally ranged from 80 to 100 percent saturation. The lowest saturation value was 69 percent under ice condition.

Like Armells Creek the nitrogen constituents showed a cyclic pattern with higher concentrations during the winter and lower values during the growing season. The cycle was not as pronounced as that of Armells Creek and may have been affected by irrigation return flows from fertilized cropland. Total phosphorus had a direct correlation with suspended-sediment concentrations, which reflects the manner in which this constituent is transported by sediment fines. The highest measured BOD of 16 mg/L on March 4, 1975, was from the highest flow sampled; probably the result of flushing of organic debris from overland runoff.

Like total phosphorus, many of the metals are sorbed and transported by sediment fines at times of surface runoff. Most of the higher values for total metals, analyzed from the water-sediment mixture, occurred on July 8, 1976, when the highest sampled sediment concentration occurred. Total iron and total aluminum had respective values of 16,000 µg/L and 8,800 µg/L on that date. Sampling for dissolved trace elements was done twice--at low and medium flows of 20 and 42 ft^3/s. Resulting values were near the average for the study area.

In classifying the water for irrigation, the sodium hazard was always low and the salinity hazard varied from medium to high. Few problems should exist in use of the water for salt-tolerant crops such as alfalfa. The water is suitable for all types of stock. However, when compared with recommended limits for drinking water, dissolved-solids and sulfate concentrations were often excessively high.


RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES

DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 11.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Rosebud Creek near Colstrip (station 5).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	24		18-233	ft^3/s
Specific conductance (at 25 deg. C)	24	1140	310-1750	umhos/cm
pH	24	8.2	7.5-8.9	units
Temperature	24	8.5	0.0-23.0	deg. C
Turbidity	24	55	5-200	JTU
Dissolved oxygen	23	91	69-110	percent
Biochemical oxygen demand	23	2.2	.4-16	mg/L
Calcium (Ca), dissolved	24	75	29-93	mg/L
Magnesium (Mg), dissolved	24	85	19-110	mg/L
Sodium (Na), dissolved	24	64	13-100	mg/L
Percent sodium	24	20	15-25	percent
Sodium-adsorption ratio	24	1.2	.5-1.7	---
Potassium (K), dissolved	24	9.4	7.4-12	mg/L
Bicarbonate (HCO_3)	24	469	132-606	mg/L
Carbonate (CO_3)	24	3	0-34	mg/L
Sulfate (SO_4), dissolved	24	270	54-420	mg/L
Chloride (Cl), dissolved	24	4.9	1.1-7.0	mg/L
Fluoride (F), dissolved	24	.5	.2-.7	mg/L
Silica (SiO_2), dissolved	24	15	7.1-21	mg/L
Dissolved solids (calculated)	24	762	198-1000	mg/L
Nitrite plus nitrate, total as N	24	.13	.00-.42	mg/L
Nitrogen, ammonia, total as N	24	.06	.00-.36	mg/L
Nitrogen, total organic as N	24	.67	.11-1.7	mg/L
Nitrogen, total kjeldahl as N	24	.73	.22-2.1	mg/L
Phosphorus, total as P	24	.11	.00-.32	mg/L
Suspended sediment	24	162	19-560	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-10	6	200-8800	ug/L
Arsenic	2	1-4	10	0-9	ug/L
Beryllium	2	0-10	10	0-10	ug/L
Boron	24	110-240	---	---	ug/L
Cadmium	2	0	10	0-10	ug/L
Chromium	2	2-<10	10	0-20	ug/L
Copper	2	0-2	10	0-130	ug/L
Iron	24	0-210	10	310-16000	ug/L
Lead	2	0-2	10	<100-100	ug/L
Lithium	2	50-55	10	40-60	ug/L
Manganese	2	10-17	10	20-600	ug/L
Mercury	2	.0-<.1	10	0-.3	ug/L
Molybdenum	2	3	10	1-6	ug/L
Nickel	2	1-7	10	0-50	ug/L
Selenium	1	0	10	0-1	ug/L
Vanadium	2	2.9-<3.0	---	---	ug/L
Zinc	2	0-<10	6	10-80	ug/L

Figure 11.--Continued.

Concentrations of suspended sediment did not always correlate well with flows. Concentrations during the summer were generally greater than concentrations of equal flows at other times of the year. This may have resulted from the natural condition of the drainage as well as sediment contributions from irrigation practices. Like dissolved solids, the greatest suspended-sediment load occurred on May 6, 1975. It was calculated as 330 tons/day, and represented a measured sediment concentration of 560 mg/L and a discharge of 218 ft^3/s (fig. 11).

Greenleaf Creek near Colstrip

Greenleaf Creek is a tributary, having only occasional flows, that enters Rosebud Creek between the two most-upstream stations (fig. 1). The channel near the station is entrenched about 4 to 8 feet and is overgrown with grass and shrubs. Several stock-pond dams are located in the 30.5 mi^2 drainage area upstream from the station.

Water was flowing on only two occasions during the study period when the station was visited. The first sample was collected on January 20, 1975, during a flow that resulted from snowmelt and rain. The second sample was collected the following March 4, after heavy snowfall and rapid melting. Water in the stream represented surface runoff and, when the ground was not frozen, inflow by water that had penetrated the soil. The base-flow component that exists in perennial streams was absent.

During both sampling times the water was a calcium bicarbonate type (fig. 12). The dissolved-solids concentrations had values of 60 and 94 mg/L for the first and second sampling, respectively. The increased concentration of the second sample was probably a result of the ground being thawed to a greater depth and the runoff water being better able to penetrate the soil and cause solution. Most of the dissolved trace metals also had comparatively low concentrations for the study area.

Unlike the dissolved constituents, many constituents analyzed from the water-sediment mixture had moderate to high values when compared with other stations in the Rosebud drainage. Levels of nitrogen were near average for the drainage as were many of the total metals. BOD and total phosphorus had high concentrations with respective averages of 10 and 0.34 mg/L, respectively.

Suspended-sediment concentrations were measured as 86 and 78 mg/L, respectively, for the two samples (fig. 12). Neither sample was thought to have been collected at the peak stage and concentrations of suspended sediment as well as many total constituents may have been much higher at times. Channel vegetation presumably prevented scouring that otherwise might have occurred.

Rosebud Creek above Pony Creek near Colstrip

This station is located about 15 miles downstream from Rosebud Creek near Colstrip. The water quality shows little change from that of the upstream station. The channel alluvium rests on the Lebo Shale Member of the Fort Union Formation and is less than 5 miles downstream from the contact with this member and the Tullock Member. Gravel, sand, and silt form the moderately stable channel bottom. Aquatic vegetation is not as abundant at this site, but the banks are lined with grasses, shrubs, and trees.

Throughout medium and low flows magnesium was dominant, followed by calcium and sodium (fig. 13). As streamflow increased both calcium and bicarbonate became more prevalent among the respective cations and anions.

The average dissolved-solids concentration increased by less than 10 percent over the upstream station. Of all constituents, only the concentration of dissolved arsenic showed an anomaly. It was analyzed from the March 5, 1975, sample and had a moderately high concentration of 28 µg/L. The sample was collected at a high flow when the relative proportion of overland runoff was high. Unfortunately, this sample was not analyzed for many of the other total and dissolved trace metals.

The suspended-sediment results were little different from those of the upstream station. The highest measured concentration was 589 mg/L on July 7, 1976, during a moderate flow of 61 ft^3/s.

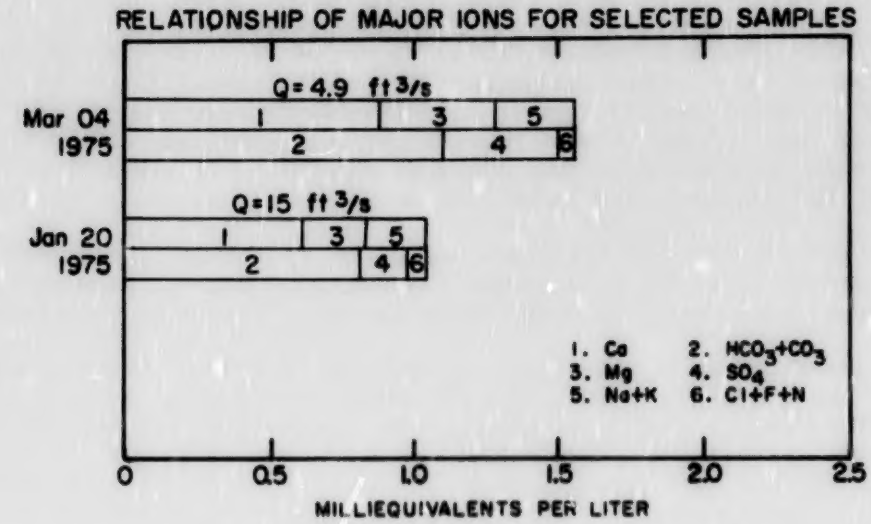
Rosebud Creek near Rosebud

This site is about 13 miles from the mouth. Channel alluvium at the site overlies the Hell Creek Formation, with the contact between this formation and the Fort Union Formation about 2 miles upstream. The channel is unstable and composed of sand and silt. Like the upstream stations, grasses, shrubs, and trees are abundant along the banks; however, little aquatic vegetation was noted.

Results of sample analyses again depicted little change from upstream for the cation ratios during reduced flows. The relative proportions of sodium increased slightly with a reduction of magnesium and calcium (fig. 14). A more notable difference was seen in the anions with sulfate increasing as bicarbonate decreased. At periods of high runoff the cation and anion percentages were about the same as those described at the station upstream.

More than half the values of dissolved-solids concentrations were slightly less than values of samples taken on the same day or a day apart at the upstream station. Sufficient data are lacking to confirm a downstream reduction in dissolved-solids concentration for this stream section; however, the data reveal that a typical downstream increase is not occurring.

Most of the in situ measurements, nutrients, and trace elements had similar patterns and values as those measured at the two upstream stations. The only noted increases were in concentrations of total metals such as iron,



SUSPENDED SEDIMENT FOR SELECTED DAYS

	Date	Time	Temperature (^{o}C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1975	Jan. 20	1230	0.5	15	86	3.5
	Mar. 04	1015	.0	4.9	78	1.0

Figure 12.--Relationships of major ions, suspended sediment, and analytical values for Greenleaf Creek near Colstrip (station 6).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	2		4.9-15	ft^3/s
Specific conductance (at 25 deg. C)	2	108	85-130	umhos/cm
pH	2	7.7	7.4-8.0	units
Temperature	2	.5	0.0-.5	deg. C
Turbidity	2	50	40-60	JTU
Dissolved oxygen	2	82	81-82	percent
Biochemical oxygen demand	2	10	9.5-11	mg/L
Calcium (Ca), dissolved	2	15	13-17	mg/L
Magnesium (Mg), dissolved	2	3.9	2.9-4.8	mg/L
Sodium (Na), dissolved	2	1.5	1.0-2.0	mg/L
Percent sodium	2	5	4-6	percent
Sodium-adsorption ratio	2	.1	.1	---
Potassium (K), dissolved	2	6.6	5.6-7.5	mg/L
Bicarbonate (HCO_3)	2	58	48-67	mg/L
Carbonate (CO_3)	2	0	0	mg/L
Sulfate (SO_4), dissolved	2	13	6.3-19	mg/L
Chloride (Cl), dissolved	2	1.7	1.3-2.0	mg/L
Fluoride (F), dissolved	2	.1	.0-.1	mg/L
Silica (SiO_2), dissolved	2	7.0	6.3-7.7	mg/L
Dissolved solids (calculated)	2	77	60-94	mg/L
Nitrite plus nitrate, total as N	2	.08	.08	mg/L
Nitrogen, ammonia, total as N	2	.26	.16-.35	mg/L
Nitrogen, total organic as N	2	1.7	1.6-1.7	mg/L
Nitrogen, total kjeldahl as N	2	1.9	1.8-2.0	mg/L
Phosphorus, total as P	2	.34	.24-.43	mg/L
Suspended sediment	2	82	78-86	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	0.	---	---	ug/L
Arsenic	1	2.	1	3	ug/L
Beryllium	1	0	1	<10	ug/L
Boron	2	80-130	---	---	ug/L
Cadmium	1	1	1	10	ug/L
Chromium	1	0	1	10	ug/L
Copper	1	19	1	50	ug/L
Iron	2	40-300	1	2300	ug/L
Lead	1	6	1	<100	ug/L
Lithium	---	---	1	10	ug/L
Manganese	1	0	1	70	ug/L
Mercury	1	.3	1	.2	ug/L
Molybdenum	---	---	1	0	ug/L
Nickel	1	0	1	<50	ug/L
Selenium	---	---	1	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	1	10	---	---	ug/L

Figure 12.--Continued.

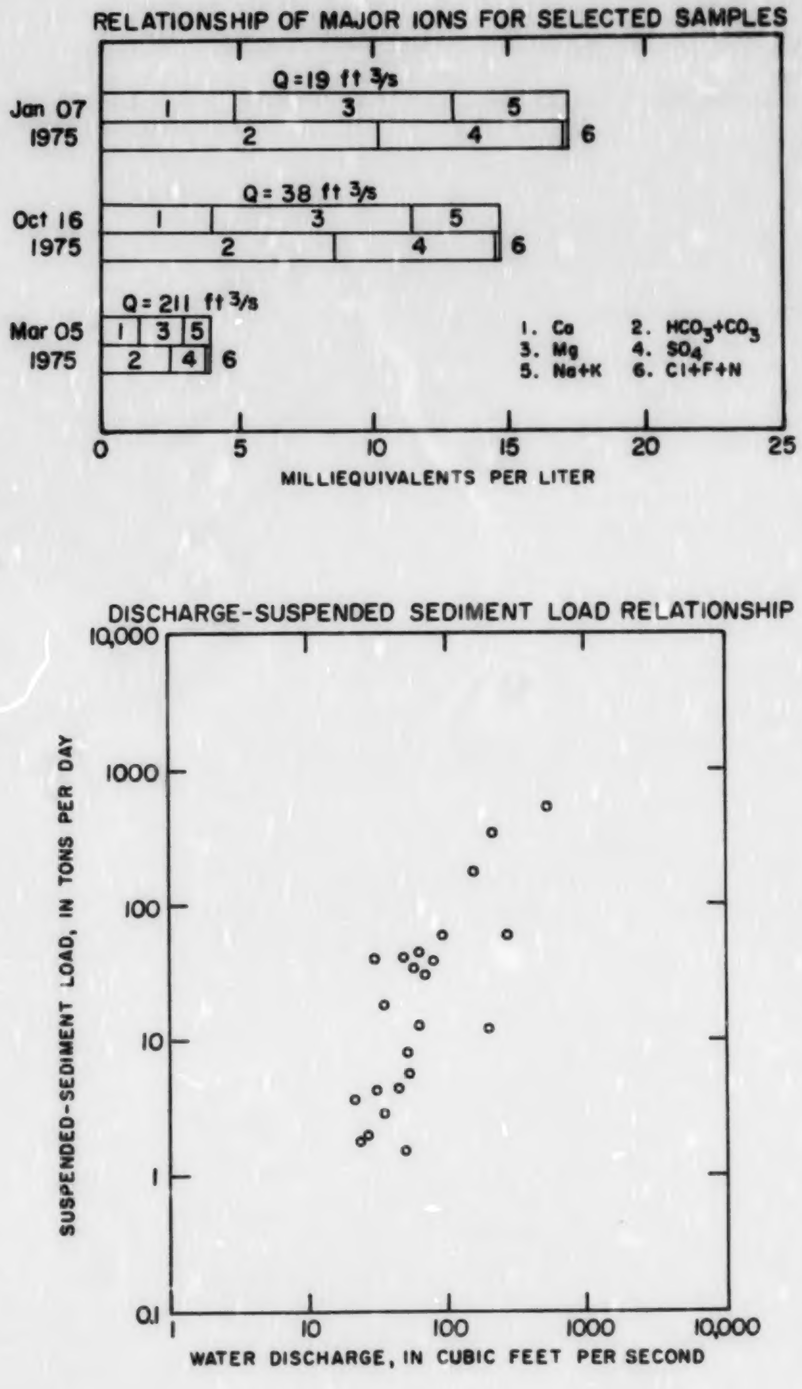
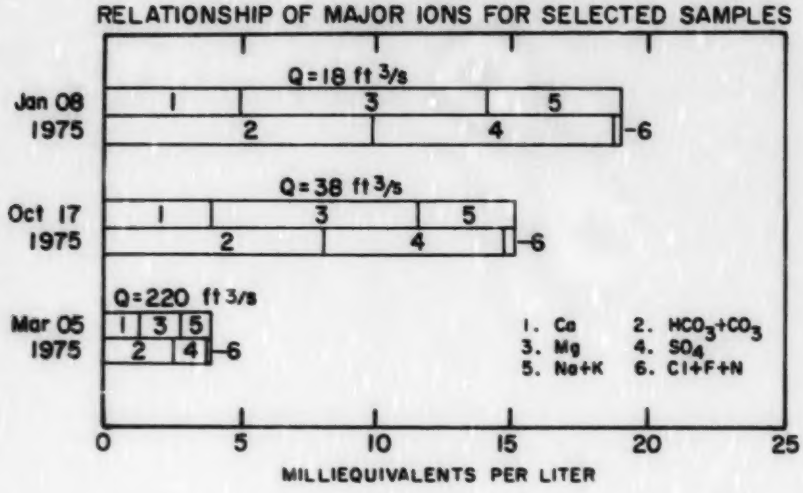


Figure 13.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Rosebud Creek above Pony Creek near Colstrip (station 7).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	24		9.4-258	ft^3/s
Specific conductance (at 25 deg. C)	24	1290	400-1900	umhos/cm
pH	24	8.2	7.5-8.8	units
Temperature	24	9.0	0.0-23	deg. C
Turbidity	24	55	7-200	JTU
Dissolved oxygen	23	90	53-118	percent
Biochemical oxygen demand	24	1.5	.2-3.1	mg/L
Calcium (Ca), dissolved	24	76	28-94	mg/L
Magnesium (Mg), dissolved	24	90	19-120	mg/L
Sodium (Na), dissolved	24	75	15-120	mg/L
Percent sodium	24	22	16-27	percent
Sodium-adsorption ratio	24	1.4	.5-2.0	---
Potassium (K), dissolved	24	9.5	1.1-12	mg/L
Bicarbonate (HCO_3)	24	469	140-617	mg/L
Carbonate (CO_3)	24	4	0-39	mg/L
Sulfate (SO_4), dissolved	24	320	62-560	mg/L
Chloride (Cl), dissolved	24	5.4	3.1-13	mg/L
Fluoride (F), dissolved	24	.6	.2-.7	mg/L
Silica (SiO_2), dissolved	24	15	7.7-22	mg/L
Dissolved solids (calculated)	24	828	627-1150	mg/L
Nitrite plus nitrate, total as N	24	.12	.00-.37	mg/L
Nitrogen, ammonia, total as N	24	.05	.00-.24	mg/L
Nitrogen, total organic as N	24	.84	.12-3.8	mg/L
Nitrogen, total kjeldahl as N	24	.88	.14-3.8	mg/L
Phosphorus, total as P	24	.10	.00-.41	mg/L
Suspended sediment	24	174	12-589	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-10	6	400-4600	ug/L
Arsenic	3	2-28	10	0-18	ug/L
Beryllium	2	0-<10	10	0-10	ug/L
Boron	24	100-240	---	---	ug/L
Cadmium	2	0	10	0-20	ug/L
Chromium	2	0-<10	10	0-20	ug/L
Copper	2	2-3	10	<10-50	ug/L
Iron	24	0-190	10	510-8200	ug/L
Lead	2	0-2	10	<100	ug/L
Lithium	2	50-53	10	40-60	ug/L
Manganese	2	10-20	10	20-310	ug/L
Mercury	2	.0-<.1	10	.0-.4	ug/L
Molybdenum	2	<3-3	10	2-4	ug/L
Nickel	2	1	10	0-<50	ug/L
Selenium	1	1	10	0-2	ug/L
Vanadium	2	1.7-<4.0	---	---	ug/L
Zinc	2	<10-30	6	10-40	ug/L

Figure 13.--Continued



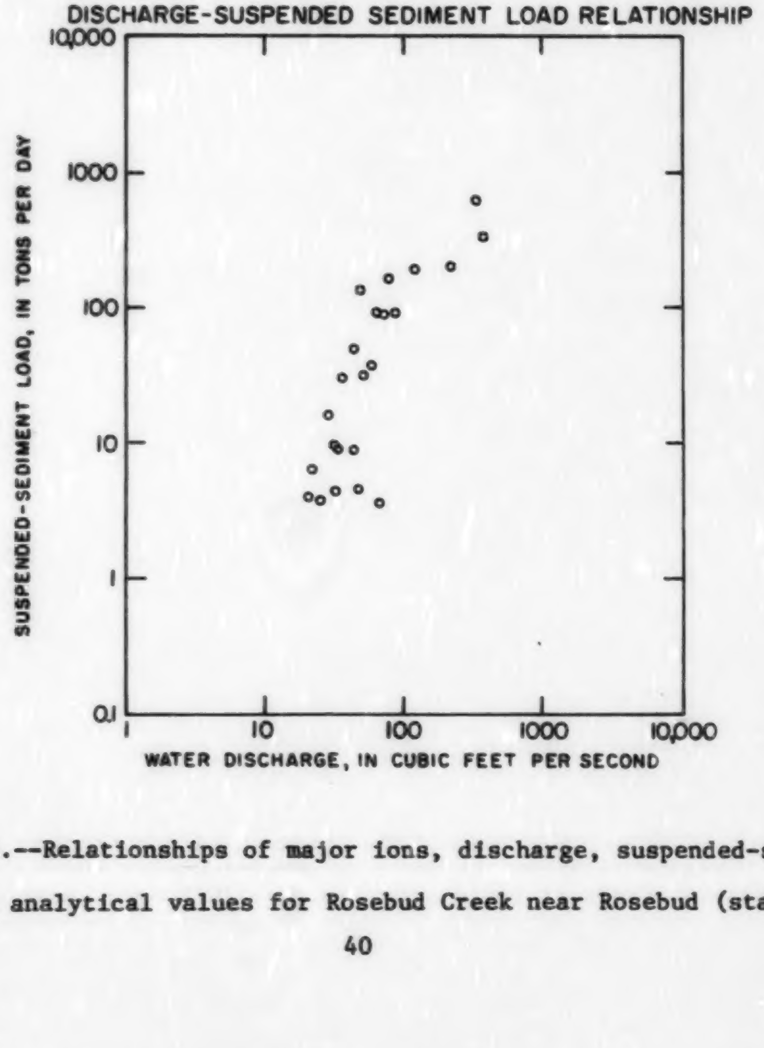


Figure 14.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Rosebud Creek near Rosebud (station 8).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	24		10-312	ft^3/s
Specific conductance (at 25 deg. C)	24	1250	350-1870	umhos/cm
pH	24	8.2	7.5-8.6	units
Temperature	24	8.5	0.0-23.0	deg. C
Turbidity	24	110	5-480	JTU
Dissolved oxygen	24	90	67-103	percent
Biochemical oxygen demand	24	1.9	.2-8.5	mg/L
Calcium (Ca), dissolved	24	73	26-98	mg/L
Magnesium (Mg), dissolved	24	88	18-120	mg/L
Sodium (Na), dissolved	24	85	21-130	mg/L
Percent sodium	24	25	18-31	percent
Sodium-adsorption ratio	24	1.6	.8-2.3	---
Potassium (K), dissolved	24	9.6	7.3-12	mg/L
Bicarbonate (HCO_3)	24	446	139-616	mg/L
Carbonate (CO_3)	24	4	0-30	mg/L
Sulfate (SO_4), dissolved	24	350	62-600	mg/L
Chloride (Cl), dissolved	24	5.4	2.7-7.5	mg/L
Fluoride (F), dissolved	24	.5	.2-.7	mg/L
Silica (SiO_2), dissolved	24	14	8.2-21	mg/L
Dissolved solids (calculated)	24	850	215-1190	mg/L
Nitrite plus nitrate, total as N	24	.11	.00-.37	mg/L
Nitrogen, ammonia, total as N	24	.04	.00-.17	mg/L
Nitrogen, total organic as N	24	.84	.23-1.6	mg/L
Nitrogen, total kjeldahl as N	24	.87	.25-1.7	mg/L
Phosphorus, total as P	24	.13	.01-.40	mg/L
Suspended sediment	24	301	18-825	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	10	6	700-6400	ug/L
Arsenic	2	2-3	10	0-8	ug/L
Beryllium	2	0-<10	10	0-10	ug/L
Boron	24	90-260	---	---	ug/L
Cadmium	2	0	10	0-<10	ug/L
Chromium	2	0-<10	10	0-35	ug/L
Copper	2	1-2	10	<10-30	ug/L
Iron	24	0-160	10	790-11000	ug/L
Lead	2	0-3	10	<100	ug/L
Lithium	2	50-53	10	30-60	ug/L
Manganese	2	0-30	10	40-420	ug/L
Mercury	2	.0-<.1	10	.0-1.2	ug/L
Molybdenum	2	<3-3	10	2-3	ug/L
Nickel	2	1-3	10	0-50	ug/L
Selenium	---	---	10	0-1	ug/L
Vanadium	2	1.6-<4.0	---	---	ug/L
Zinc	2	10	6	20-50	ug/L

Figure 14.--Continued.

manganese, and aluminum. The higher values relate to increases between the two sites in suspended sediment, which transported the constituents.

The highest measured suspended-sediment concentration was 825 mg/L in August 1975 and the lowest was 18 mg/L in February 1975 (fig. 14). Concentrations during the spring and summer were frequently between 300 and 800 mg/L. A moderate gain in suspended sediment appears to occur as water passes this station. Channel conditions, turbidity, and water coloration also confirm greater amounts of sediment.

Rosebud Creek at mouth near Rosebud

This station was sampled 0.8 mile upstream from the mouth at the stream-gaging station. The channel is entrenched in the vicinity of the station and during low flows has alternating sections of pools and riffles. The bottom of the pools is composed of sediment fines and the riffles are cobbles. The alluvium is underlain by the Hell Creek Formation. Grasses and shrubs are present along the bank, but trees are nearly absent. Periphyton was observed on the stream bottom at times, but was visibly absent at other times.

The 1975-water-year hydrograph (fig. 15) shows that this station exhibits slightly lower flows during the fall and higher flows throughout the spring and early summer. For the 1975 water year the lowest recorded flow was 7.4 ft^3/s and the highest about 1,000 ft^3/s. The minimum and maximum sampled flows during the period of study were 5.7 ft^3/s on September 7, 1976, and 916 ft^3/s on May 7, 1975.

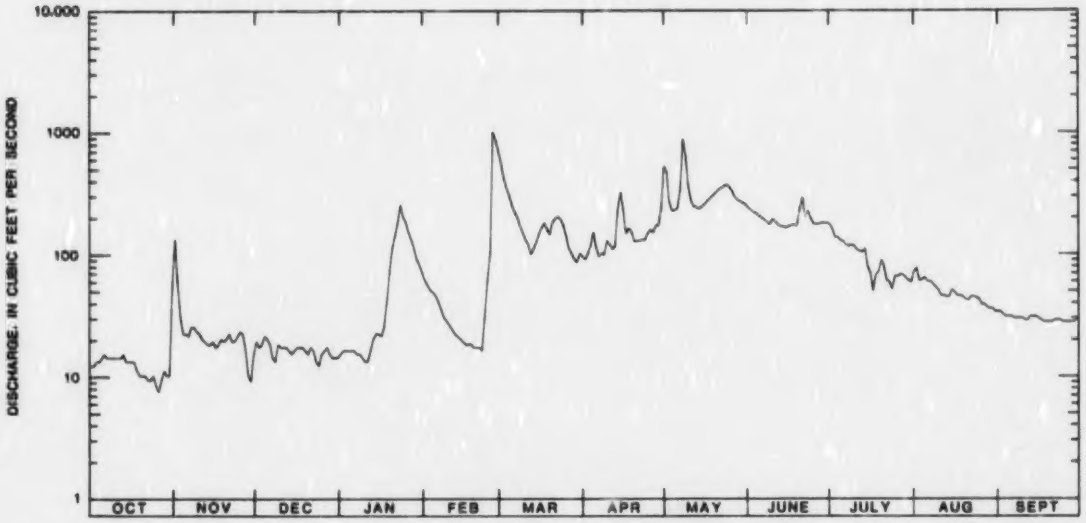


Figure 15.--Hydrograph of stream discharge for Rosebud Creek at mouth near Rosebud, 1975 water year.

When sampled at and near base flow, the water contained principally magnesium, bicarbonate, and sulfate (fig. 16). Magnesium accounted for nearly 50 percent of the cation milliequivalents with the rest about equally divided between calcium and sodium. The bicarbonate and sulfate anions were nearly equal. As streamflow increased from base flow through medium to high flows, calcium became more dominant as magnesium decreased. At the same time, bicarbonate increased with a reduction in sulfate.

Dissolved-solids concentrations for the section of Rosebud Creek that was sampled were generally greatest at this station. The highest measured dissolved-solids concentration was 1,270 mg/L on September 7, 1976. The maximum calculated dissolved-solids load of 935 tons/day occurred May 7, 1975, during the highest sampled flow.

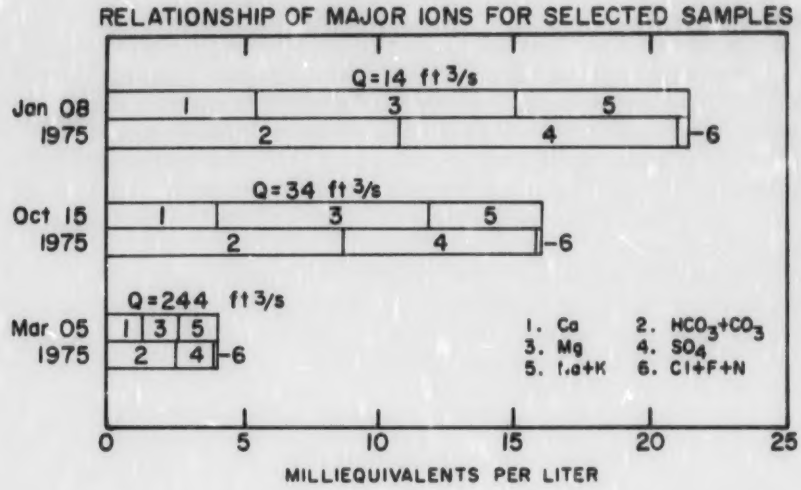
Most of the in situ measurements had only slight differences from those upstream. Dissolved oxygen exceeded the saturation point on five occasions--most of them during the summer. Generally dissolved oxygen was near 90 percent of saturation. The pH changed little from upstream, but did exhibit a weak indirect correlation to streamflow. Observations indicate a more pronounced coloration of the water and the average turbidity nearly doubled from the upstream station.

The nutrients and BOD analyzed from the water-sediment mixture all showed a direct relationship to suspended sediment. The nitrogen constituents showed cyclical patterns. The highest total nitrogen concentration was 6.2 mg/L on May 7, 1975, and was predominantly in the form of organic nitrogen. Total phosphorus during the same sampling was 2.3 mg/L, the maximum concentration for any of the Rosebud stations. The highest BOD of 8.8 mg/L was sampled from a moderately high flow on January 20, 1975. The higher values seemed to be more prevalent during late winter and early spring when surface runoff was fast and, because of frozen ground, had little chance to penetrate deeply into the soil.

Concentrations for some total trace elements showed increases over upstream sampling. The increases were due to availability of sediment that acted as a transport mechanism. Dissolved trace metals remained about the same as the values found upstream.

Although both the average SAR and dissolved-solids concentration increased respectively by 0.7 and 92 mg/L, the changes were not significant enough to affect the water use as described for Rosebud Creek near Colstrip. In comparing all water-quality properties for the Rosebud stations, increased sediment at this site is the only property that might cause additional problems in present uses.

During periods of high flows suspended-sediment concentration increased substantially when compared with the next station upstream. At low and medium flows the increase was not as prevalent and tended to be erratic. An atypical situation occurred on October 10, 1974, during the lowest sampled flow when the third highest sediment concentration of 1,160 mg/L was measured.



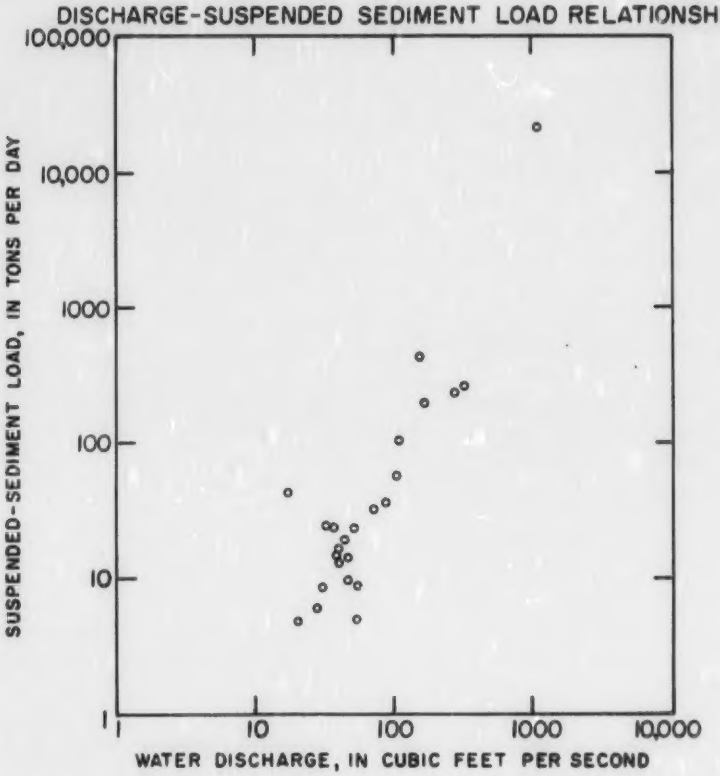


Figure 16.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Rosebud Creek at mouth near Rosebud (station 9).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	25		5.7-916	ft^3/s
Specific conductance (at 25 deg. C)	25	1270	330-2060	umhos/cm
pH	25	8.2	7.5-8.8	units
Temperature	25	9.0	0.0-25.0	deg. C
Turbidity	25	220	5-2500	JTU
Dissolved oxygen	25	96	67-113	percent
Biochemical oxygen demand	25	2.1	.4-8.8	mg/L
Calcium (Ca), dissolved	25	71	25-110	mg/L
Magnesium (Mg), dissolved	25	84	12-120	mg/L
Sodium (Na), dissolved	25	98	24-190	mg/L
Percent sodium	25	29	19-63	percent
Sodium-adsorption ratio	25	1.9	.9-3.8	---
Potassium (K), dissolved	25	9.6	5.0-13	mg/L
Bicarbonate (HCO_3)	25	438	133-636	mg/L
Carbonate (CO_3)	25	4	0-21	mg/L
Sulfate (SO_4), dissolved	25	350	68-620	mg/L
Chloride (Cl), dissolved	25	5.2	2.2-7.6	mg/L
Fluoride (F), dissolved	25	.6	.2-1.1	mg/L
Silica (SiO_2), dissolved	25	13	7.5-21	mg/L
Dissolved solids (calculated)	25	854	220-1270	mg/L
Nitrite plus nitrate, total as N	25	.12	.00-.45	mg/L
Nitrogen, ammonia, total as N	25	.04	.00-.18	mg/L
Nitrogen, total organic as N	25	1.1	.22-5.7	mg/L
Nitrogen, total kjeldahl as N	25	1.1	.26-5.7	mg/L
Phosphorus, total as P	25	.25	.02-2.3	mg/L
Suspended sediment	25	552	35-7240	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	<7-<20	6	710-4300	ug/L
Arsenic	3	0-3	11	0-10	ug/L
Beryllium	2	<10-10	11	0-10	ug/L
Boron	25	100-290	---	---	ug/L
Cadmium	2	0	11	0-20	ug/L
Chromium	2	<10-10	11	0-40	ug/L
Copper	2	0-2	11	<10-60	ug/L
Iron	25	0-140	11	1000-32000	ug/L
Lead	2	0-1	11	<100-100	ug/L
Lithium	2	40-56	11	30-60	ug/L
Manganese	2	30	11	60-570	ug/L
Mercury	2	.0-<.1	11	.0-1.2	ug/L
Molybdenum	2	2-<3	11	0-3	ug/L
Nickel	2	0-3	11	0-100	ug/L
Selenium	1	1	11	0-1	ug/L
Vanadium	2	1.6-<4.0	---	---	ug/L
Zinc	2	0-20	6	10-40	ug/L

Figure 16.--Continued.

The station upstream on the same day, at a nearly equal flow, had a concentration of 100 mg/L. The highest measured sediment concentration was 7,240 mg/L on May 7, 1975. The sample was collected from the highest sampled flow and had a calculated suspended-sediment load of 17,900 tons/day (fig. 16). This particular flow was near the peak of a high spring runoff and the sample probably represents a suspended-sediment load that was near the maximum for the 1975 water year.

Areal correlation

Hydrographs from the upstream and downstream stations (figs. 10 and 15) show similar major trends in streamflow with some minor differences. Base flow and surface runoff from snowmelt and storms combine to give high flows from early spring through early summer. A gradual reduction occurs throughout mid-summer as water in the soil is depleted. During the rest of the year base flow is the major water source of the stream. Natural flow patterns are also modified by irrigation withdrawals along parts of the middle and lower drainage and by irrigation return flow which may be subsurface.

A comparison of the hydrographs shows that streamflow was both lost and gained during different periods. The losses might be attributed to evaporation and transpiration; however, both processes should cause an increase in dissolved-solids concentration--a condition that was not always evident. At least part of the losses seem to be a result of subsurface outflow from the stream. The gains in streamflow between the upstream and downstream stations are typical of most streams and are related to the condition described in the preceding paragraph.

Only slight differences were found in the chemical character of the water from the upstream station through the second and third stations at times of low and medium flows. Larger changes, however, did occur from the third station to the station at the mouth. Figure 17A illustrates major-ion relationships during a period of base flow. Magnesium and bicarbonate were the principal cation and anion, respectively, at the three upstream stations, although sulfate gradually increased as the water flowed downstream. At the mouth of Rosebud Creek sodium had increased significantly as magnesium decreased and sulfate became about equal to bicarbonate. Comparison of the major ions at different flows shows that the surface-runoff water was a calcium bicarbonate type with reduced dissolved-solids concentration. This was also true of water analyzed from Greenleaf Creek during the two periods of surface runoff.

The vertical extent of the major-ion graph (fig. 17A) shows that the dissolved-solids concentration increased between the first and second stations and between the third and fourth stations. The concentration remained almost constant between the two middle stations. This trend was typical of most sample results at low and medium flows.

The variations described above in streamflow, water types, and dissolved-solids concentration are primarily a function of the basin geology and in part

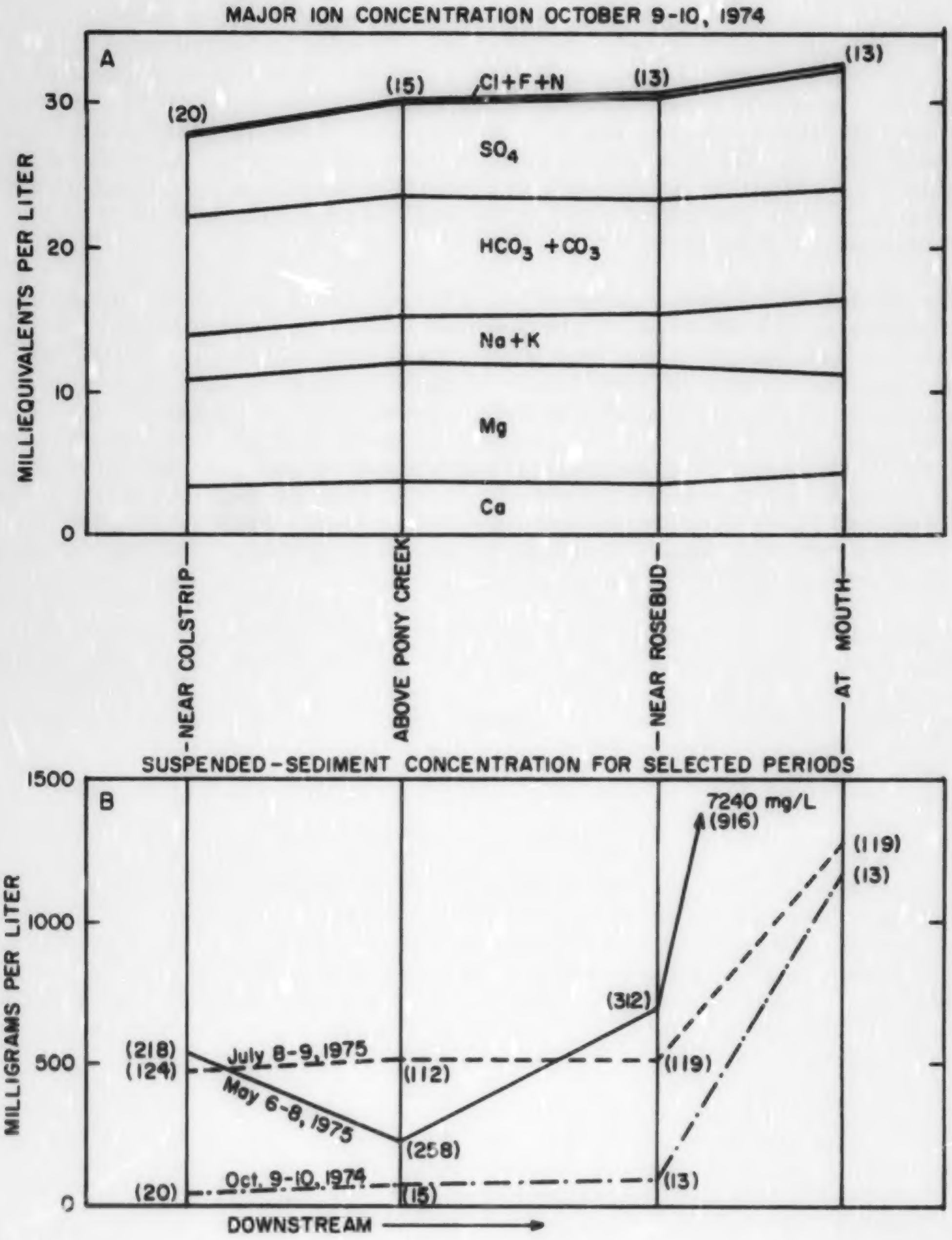


Figure 17.--Concentrations of (A) dissolved constituents and (B) suspended sediment for selected periods on Rosebud Creek. Numbers in parentheses represent stream discharge at time of sampling, in cubic feet per second.

can be correlated with geologic formations. Changes in water type seem to be more prevalent where the channel intersects the Hell Creek Formation--between the two downstream stations. The abnormal consistency in dissolved-solids concentration between the middle stations occurred where the stream has eroded through the Lebo and Tullock Members of the Fort Union Formation. A detailed investigation might show that certain aquifers and other lithologic sections within the named rock units are the controls rather than the entire rock units themselves.

The suspended-sediment graph (fig. 17B) illustrates three periods in which samples were collected at the Rosebud Creek stations. The October and July samples were taken at low and high flows, respectively, and the May samples were from a medium high flow. Because of the variability of sediment movement, more frequent sampling would be necessary to understand the sediment transport, but some trends can be seen. All three sample sets show little change in concentration between the first and third stations and greater increases between the third and fourth stations. During the July set of samples, however, the only station sampled at near peak flow was the downstream station. Had it been possible to sample the peak flows at all the stations, a more uniform curve might have resulted.

Sediment sources during high flows were from both overland runoff and channel scour. Pools, although not as numerous as on Armells Creek, acted as sediment traps at lower flows and released sediment as stream velocities increased. Variations in suspended-sediment concentration were not always related to changes in stream discharge.

Tongue River basin

The Tongue River flows north from its headwaters along the eastern slope of the Bighorn Mountains in Wyoming to its confluence with the Yellowstone River (fig. 1). The valleys of the Tongue River and its major tributaries are wide and surrounded by broken uplands that are generally drained by intermittent streams. Vegetation often consists of trees and grass in the uplands and sagebrush and grass in the valleys. Abrupt slopes often divide the uplands from the valleys.

The part of the stream examined extends from the Tongue River Dam, just north of the Montana-Wyoming border, to the mouth of the river and includes some perennial and intermittent tributaries. The channel, for the entire distance, is in alluvium which locally has a thickness of 100 feet and a width of almost 2 miles. For about two-thirds of the distance from the dam to the mouth, the channel alluvium rests on the Tongue River Member of the Fort Union Formation. In a relatively short distance the channel transects the Lebo Shale Member and is then in the Tullock Member to the mouth.

Land use is mostly related to agriculture. Livestock was the original industry in the area, with farming of irrigated cropland becoming more important after the construction of the Tongue River Dam in 1939. Both alfalfa and sugar beets are important commercial crops. Near the Tongue River Reservoir and upstream, large quantities of coal are being extracted. Coal mining and related activities are planned throughout the basin.

The Tongue River Dam modifies many of the natural water-quality conditions. With a capacity of 68,000 acre-feet, or about 18 percent of the average annual inflow, the reservoir moderates streamflow and causes mixing of dissolved constituents. The result is generally a reduction in range of concentration of many constituents. Many of the physical properties of the water are affected in a like manner. Most of the suspended sediment carried by the river upstream from the reservoir settles to the bottom. In turn, those constituents transported by the sediment are, at least temporarily, lost to the stream. The reservoir, like most natural and artificial impoundments, acts as a "sink" for many constituents.

During November 1975, for a period of several days, the major outflow structure of the dam was closed for repair. The small quantity of water that bypassed the outflow structure was augmented by contributions from tributaries and ground-water inflow between the dam and the mouth. Samples collected during November 11-12 were part of a low-flow quantity and quality study by R. D. Hutchinson and A. J. Boettcher (written commun., 1976).

Four water-quality stations are maintained on the main river between the dam and the mouth (fig. 1). Three of the stations are also operated as continuous-recording streamflow stations and one as a daily suspended-sediment station. Other water-quality stations are present on five perennial and several intermittent tributaries. The following discussion will consider all main-stem stations and two of the larger perennial tributaries in downstream order. Ten small tributary streams are grouped and discussed later. Pumpkin Creek, a major tributary of the Tongue River, is discussed in a separate section of the report.

Tongue River at Tongue River Dam near Decker

The water-quality data collection began at this Tongue River site (station 10) in October 1975. Water samples were collected at the gaging station about 0.5 mile downstream from the Tongue River Dam. The stable channel is composed mostly of gravel and the banks are lined with grasses and cottonwood trees. Channel alluvium rests on the Tongue River Member of the Fort Union Formation. During parts of the year, notably in the summer, long filaments of periphyton are present and clog the channel.

The streamflow hydrograph (fig. 18) shows the release pattern during the 1975 water year. The absence of fluctuations depicts the buffering action the reservoir has to streamflow. The mean daily flow of 782 ft^3/s for the 1975 water year is considerably above the 463 ft^3/s for the 36-year average.

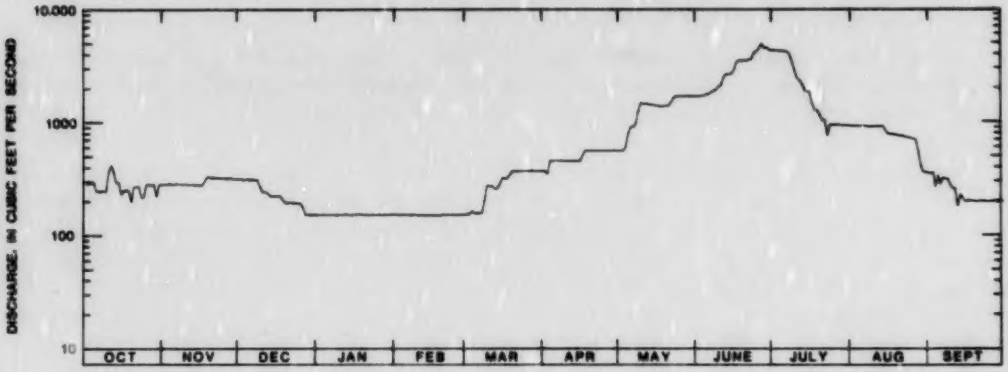


Figure 18.--Hydrograph of stream discharge
for Tongue River at Tongue River Dam near Decker, 1975 water year.

Water types varied between two extremes caused by (1) release of stored water primarily from the base-flow component of the upstream drainage, and (2) release of water composed of the base-flow component mixed with a large percentage of spring runoff water. When condition 1 predominated, the cation ratio showed magnesium at 44 percent, calcium at 37 percent, and sodium at 19 percent (fig. 19). The anions were almost equally divided between bicarbonate and sulfate. Water resulting from condition 2 had calcium and magnesium percentages reversed with sodium unchanged. Bicarbonate and sulfate assumed a 62 to 37 ratio. Thus, spring runoff was a calcium bicarbonate type water and it mixed throughout parts of the year in changing amounts with the base-flow component to cause the observed variations in water type.

Dissolved solids, like water type, had extreme values and variations that were influenced by base-flow and spring-runoff conditions. The minimum dissolved-solids concentration was analyzed from the July 7, 1976, sample at 195 mg/L. This flow occurred after the spring runoff had flushed the reservoir. The maximum concentration of 617 mg/L was measured from the sample collected on April 6, 1975, prior to spring runoff, and after base flow had contributed to the reservoir during the fall and winter periods.

Some of the other measured properties were influenced by mixing of water in the reservoir or by the manner in which water was released from the dam. Water was withdrawn from near surface to 50 feet below the surface, depending on the reservoir stage. The range in water temperature was less than it might have been without the dam. Aeration was good and no dissolved-oxygen concentrations were measured below 92 percent saturation and none above 103 percent. Water pH had its lowest value of 7.9 after the spring runoff had flushed the reservoir, and bicarbonate became a more dominant species among the anions. Although turbidity was low, measurements always showed values greater than zero. The turbidity was probably associated with biological processes (plankton growth) in the reservoir and movement of suspended sediment through the reservoir.

Total nitrogen, mostly organic nitrogen, had its highest concentration of 3.8 mg/L from the February 3 sample. The concentration decreased significantly in March and generally declined until spring. The 3.8 mg/L value was much higher than total nitrogen measured at the reservoir inflow during the year. Normal winter-time increases of nitrogen, plus reduced primary productivity and liberation of nitrogen to the water, may have caused the anomaly. Phosphorus and many trace elements that are sorbed and transported by fine suspended-sediment particles showed moderate to low values with no cyclical patterns. Likewise, concentrations of the dissolved trace elements were relatively low.

Water stored and used for irrigation is predominantly from spring runoff and summer flows when the quality of irrigation water is best. Water released from the dam during the late spring and early summer months had a low sodium hazard and a low-to-medium salinity hazard. Through June, July, and August, dissolved-solids concentration averaged 240 mg/L and boron was less than 100 μg/L. Throughout the entire year water would be suitable for consumption by all types of livestock; however, it was very often near or above the recommended limits of dissolved-solids concentration when considered for human consumption. Sulfate was beyond the recommended upper limit on one occasion and hardness would create problems for some uses. The water below the dam and downstream is reported to support a good fish population with an abundance of rainbow and brown trout.

Concentrations of suspended sediment were less than 20 mg/L for 80 percent of the samples and never exceeded 50 mg/L. Although the concentrations were low compared to other stations, it does indicate that not all sediment was removed in the reservoir. Insufficient time for sediment to settle, sediment stratification within the reservoir, and below-water-surface withdrawal at the dam are conditions that account for some of the measured sediment. Owing to reduced suspended-sediment loads, channel degradation occurs downstream from the dam and some increase in suspended sediment may take place in the channel between the dam and the station.

Hanging Woman Creek near Birney

Hanging Woman Creek near Birney was sampled at the gaging station (station 11) 3.3 miles upstream from the mouth. The drainage area upstream from the station is 470 mi^2, of which about 1,240 acres is irrigated. The channel near the station is stable and composed of cobbles with some sand and silt. Grasses, shrubs, and trees are abundant along the banks and periphyton was found in the channel except during long periods of ice cover.

The 1975-water-year hydrograph (fig. 20) shows that flows of about 1 ft^3/s occurred throughout the fall and early winter. After mid-January, storms, snowmelt, and the normal spring runoff all contributed to streamflow until early summer when a gradual decline to base flow began. Upstream use of water for irrigation modified normal streamflow patterns during the spring and early summer. The highest flow sampled was 125 ft^3/s on March 20, 1975.

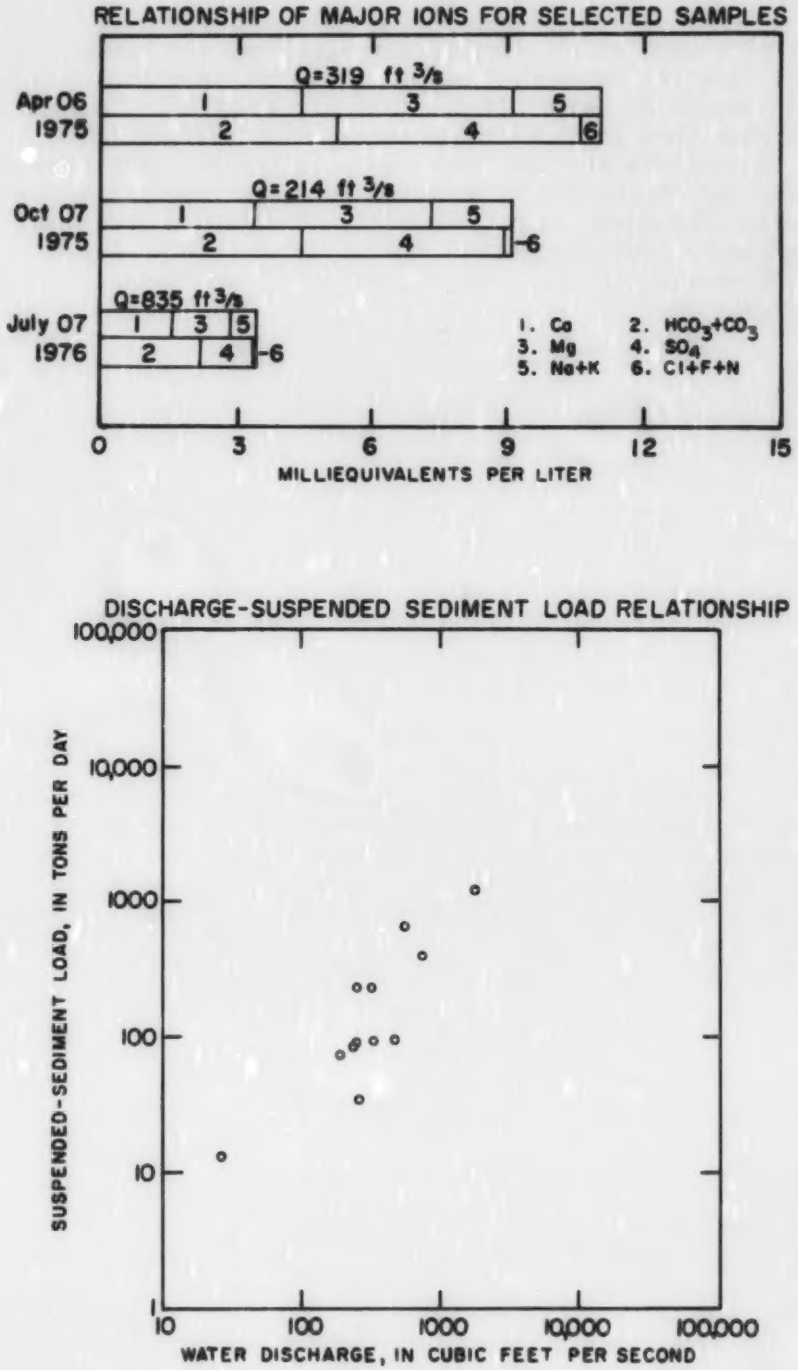


Figure 19.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Tongue River at Tongue River Dam near Decker (station 10).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	12		25-1510	ft^3/s
Specific conductance (at 25 deg. C)	12	706	330-945	umhos/cm
pH	12	8.2	7.9-8.5	units
Temperature	12	9.5	2.0-22.0	deg. C
Turbidity	12	5	2-10	JTU
Dissolved oxygen	12	100	92-103	percent
Biochemical oxygen demand	12	1.0	.4-1.8	mg/L
Calcium (Ca), dissolved	12	63	29-81	mg/L
Magnesium (Mg), dissolved	12	41	16-58	mg/L
Sodium (Na), dissolved	12	32	13-46	mg/L
Percent sodium	12	17	14-20	percent
Sodium-adsorption ratio	12	.8	.5-1.0	---
Potassium (K), dissolved	12	3.7	1.7-4.9	mg/L
Bicarbonate (HCO_3)	12	253	131-332	mg/L
Carbonate (CO_3)	12	1	0-7	mg/L
Sulfate (SO_4), dissolved	12	180	61-260	mg/L
Chloride (Cl), dissolved	12	3.3	1.1-4.6	mg/L
Fluoride (F), dissolved	12	.3	.1-.3	mg/L
Silica (SiO_2), dissolved	12	5.1	1.0-10	mg/L
Dissolved solids (calculated)	12	451	195-617	mg/L
Nitrite plus nitrate, total as N	12	.11	.00-.28	mg/L
Nitrogen, ammonia, total as N	12	.05	.00-.10	mg/L
Nitrogen, total organic as N	12	.67	.19-3.5	mg/L
Nitrogen, total kjeldahl as N	12	.72	.29-3.6	mg/L
Phosphorus, total as P	12	.04	.00-.07	mg/L
Suspended sediment	12	21	6-50	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	20	5	60-320	ug/L
Arsenic	1	1	5	0-1	ug/L
Beryllium	1	0	5	0-10	ug/L
Boron	12	40-150	---	---	ug/L
Cadmium	1	0	5	0-10	ug/L
Chromium	1	2	5	0-10	ug/L
Copper	1	2	5	0-10	ug/L
Iron	12	0-980	5	50-450	ug/L
Lead	1	1	5	<100	ug/L
Lithium	1	20	5	10-40	ug/L
Manganese	1	10	5	50-90	ug/L
Mercury	1	.0	5	.0-.1	ug/L
Molybdenum	1	2	5	0-2	ug/L
Nickel	1	2	5	<50-50	ug/L
Selenium	1	1	5	0-1	ug/L
Vanadium	1	1.6	---	---	ug/L
Zinc	1	2	5	0-20	ug/L

Figure 19.--Continued

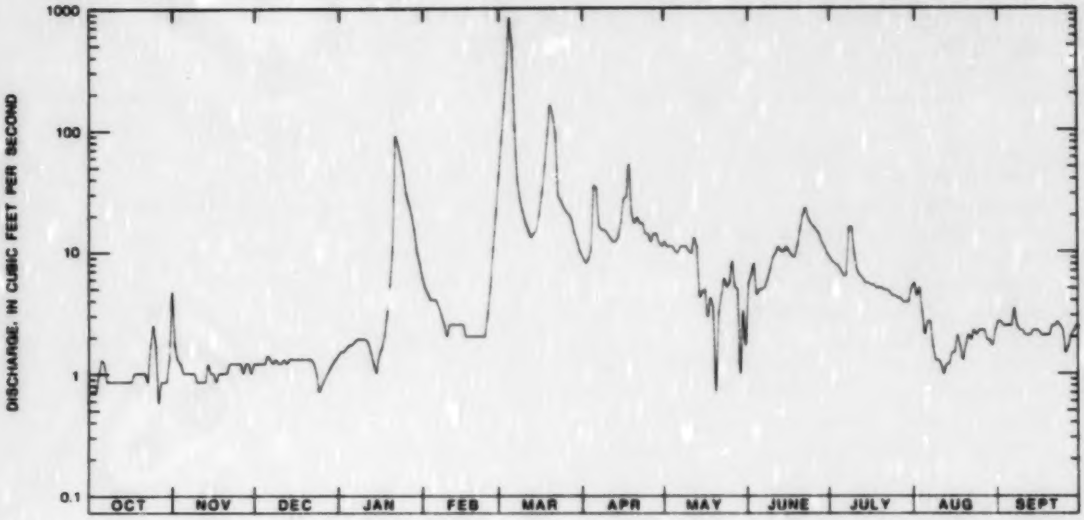


Figure 20.--Hydrograph of stream discharge for Hanging Woman Creek near Birney, 1975 water year.

During low and medium flows (less than 20 ft^3/s) the water was a sodium sulfate type (fig. 21). The cation ratio was in contrast to that of the Tongue River water where much less sodium was found. During high flow, calcium and bicarbonate became the dominant cation and anion, respectively, and are indicative of the water type from surface runoff.

Dissolved-solids concentrations commonly ranged from 1,500 to 2,000 mg/L. This is approximately a three-fold increase over the water in the Tongue River downstream from the mouth of Hanging Woman Creek. Calculations from the limited sampling during the study show that Hanging Woman Creek increased the dissolved-solids concentration in the Tongue River by about 4 percent, although the contribution to streamflow was less than 2 percent. The highest calculated dissolved-solids load was 135 tons/day on March 20, 1975, and the daily average for those days sampled was 25 tons/day.

Most of the in situ measurements had relatively moderate ranges. Dissolved oxygen often had some depletion both during ice conditions and at times of morning sampling in the summer when respiration exceeded photosynthetic production. Water pH was constantly in the range of 8.0 to 8.3 and only during times of surface runoff did it drop below this range. The lowest measured pH was 7.4.

Total nitrogen, primarily in the organic form, fluctuated and followed only a very weak cyclical pattern with maximums and minimums, respectively, in the winter and summer. BOD, on two occasions, had values of 10 mg/L--both occurred about a year apart at times in late winter when runoff was over partly frozen surfaces. The highest measured concentration of total phosphorus was 0.78 mg/L from the July 9, 1975, sample and coincidental with the highest sediment concentration. Throughout the year total phosphorus and suspended-sediment concentration had parallel patterns.

The high dissolved-solids concentration in the water causes a high salinity hazard when classified for irrigation. Flood irrigation is used upstream on crops such as hay and alfalfa; however, it is necessary to flood with additional water to leach the salts and to prevent sodium accumulation. The water is suitable for all stock consumption, but is considerably above the recommended upper limits in both dissolved solids and sulfate when considered for human consumption.

More than half the samples had suspended-sediment concentrations of less than 50 mg/L. Stability of the channel and vegetative cover along the banks prevent excessive degradation. The highest measured concentration was 470 mg/L on July 9, 1975, at a relatively low discharge of 9.5 ft^3/s. The largest calculated load was 114 tons/day (fig. 21) on March 20, 1975.

Tongue River below Hanging Woman Creek

Samples were collected at a distance below Hanging Woman Creek (station 12) where mixing was thought to be good. The channel, composed of gravel, sand, and silt is relatively stable, but shows some evidence of lateral erosion during times of high flows. Suspended filaments of algae were common as were dense growths of diatoms on the bottom. Ice cover was present during the winter periods.

Streamflow at this station is regulated by the Tongue River Dam upstream. A number of intermittent tributaries and Hanging Woman Creek with its perennial flow enter the Tongue River between the dam and this station. R. D. Hutchinson and A. J. Boettcher (written commun., 1976) show evidence of some upstream ground-water inflow. Although significant at times, both surface and ground-water inflows downstream from the Tongue River Dam account for only small amounts of the total annual flow. Irrigation of croplands is practiced extensively upstream and minor flow variations sometimes result from the influence.

Throughout medium flows, the water was much the same type (fig. 22) as that released from the dam. As discharges were reduced, the ground-water inflow within the reach accounted for increasing portions of the total flow, and influenced the water type by contributing higher amounts of sodium and sulfate. Conversely, when intermittent streams were flowing as a result of surface runoff, the cation and anion ratios differed from those at the reservoir outlet by exhibiting higher percentages of calcium and bicarbonate, respectively.

The dissolved-solids concentrations between the dam and the station were influenced in much the same way as the water type. At lower discharges the inflow from ground water had a much greater effect than at other times and elevated the concentrations. Contribution to the river from surface-water runoff downstream from the dam diluted the river water and lowered the dissolved-solids concentration.

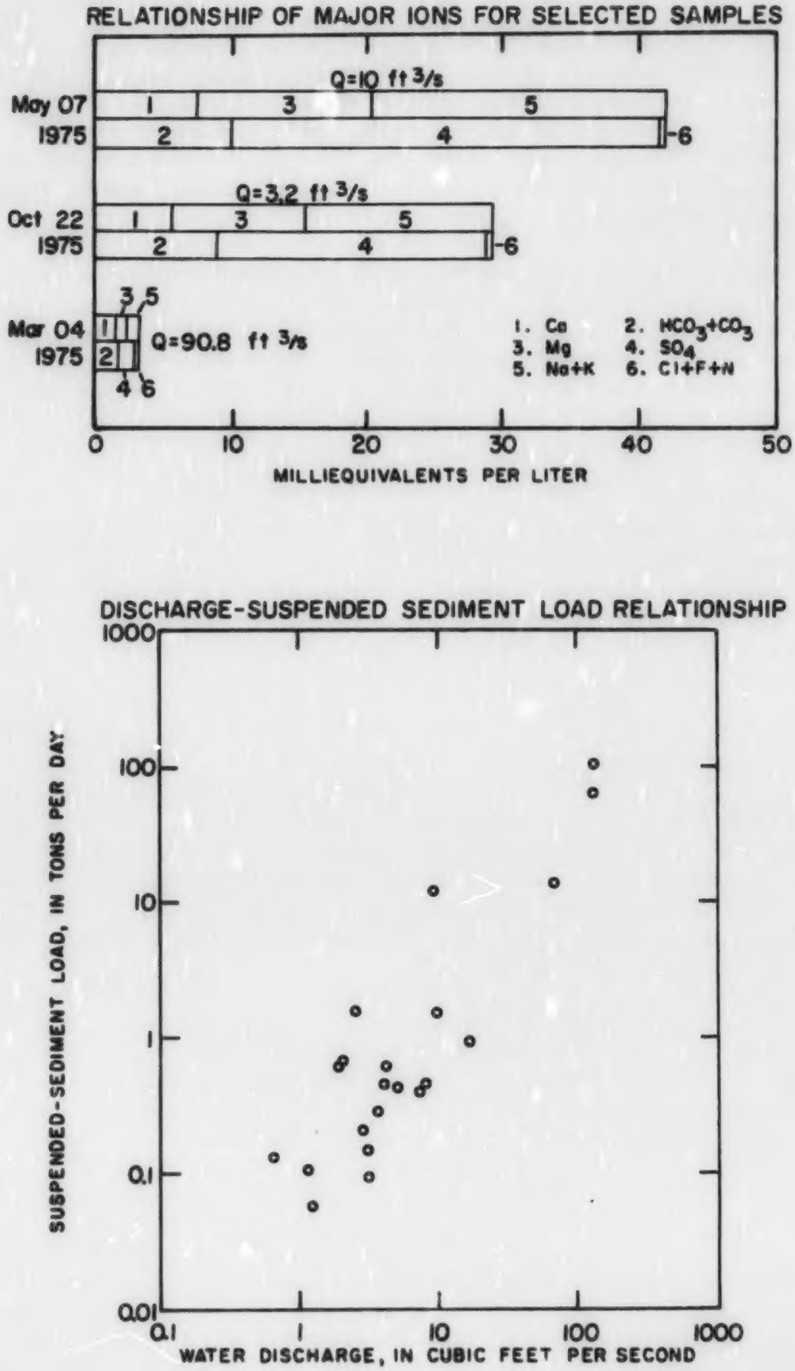


Figure 21.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Hanging Woman Creek near Birney (station 11).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	27		0.59-125	ft^3/s
Specific conductance (at 25 deg. C)	26	2270	240-3700	umhos/cm
pH	26	8.1	7.4-8.4	units
Temperature	27	8.0	0.0-22.0	deg. C
Turbidity	25	50	4-400	JTU
Dissolved oxygen	26	86	62-104	percent
Biochemical oxygen demand	26	2.8	.1-10	mg/L
Calcium (Ca), dissolved	26	97	31-150	mg/L
Magnesium (Mg), dissolved	26	110	11-170	mg/L
Sodium (Na), dissolved	26	280	17-490	mg/L
Percent sodium	26	46	23-50	percent
Sodium-adsorption ratio	26	4.6	.7-6.6	---
Potassium (K), dissolved	26	14	7.6-16	mg/L
Bicarbonate (HCO_3)	26	519	89-669	mg/L
Carbonate (CO_3)	26	0	0	mg/L
Sulfate (SO_4), dissolved	26	840	57-1500	mg/L
Chloride (Cl), dissolved	26	10	2.5-14	mg/L
Fluoride (F), dissolved	26	.8	.1-1.3	mg/L
Silica (SiO_2), dissolved	26	15	6.7-22	mg/L
Dissolved solids (calculated)	26	1630	176-2630	mg/L
Nitrite plus nitrate, total as N	26	.11	.00-.40	mg/L
Nitrogen, ammonia, total as N	26	.05	.00-.19	mg/L
Nitrogen, total organic as N	26	.89	.20-3.7	mg/L
Nitrogen, total kjeldahl as N	26	.94	.21-3.7	mg/L
Phosphorus, total as P	25	.12	.00-.78	mg/L
Suspended sediment	26	90	12-470	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-40	6	90-640	ug/L
Arsenic	2	0-1	11	0-4	ug/L
Beryllium	2	0-<10	10	0-10	ug/L
Boron	26	120-820	---	---	ug/L
Cadmium	2	1-<35	11	<10-20	ug/L
Chromium	2	6-<10	11	0-14	ug/L
Copper	2	2-<3	11	0-20	ug/L
Iron	26	0-1500	11	390-3600	ug/L
Lead	2	5-<10	11	<100-100	ug/L
Lithium	2	90-100	11	20-120	ug/L
Manganese	2	20-30	11	40-390	ug/L
Mercury	2	0-<.1	11	.0-.4	ug/L
Molybdenum	2	<4-5	11	1-4	ug/L
Nickel	2	3-<8	11	0-50	ug/L
Selenium	1	1	11	0-2	ug/L
Vanadium	2	.7-<5	---	---	ug/L
Zinc	2	10-20	6	10-60	ug/L

Figure 21.--Continued

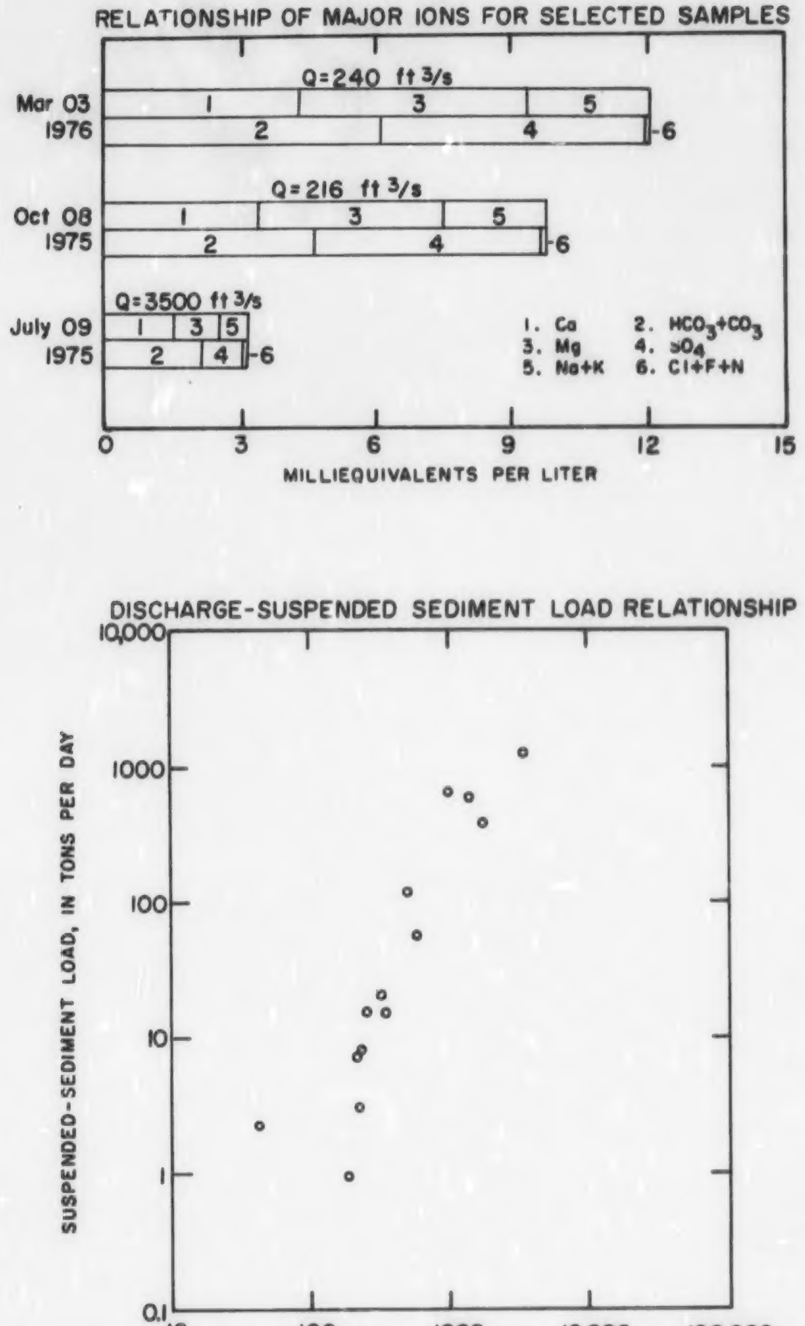


Figure 22.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Tongue River below Hanging Woman Creek near Birney (station 12).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	24		45-3500	ft^3/s
Specific conductance (at 25 deg. C)	24	729	280-1310	umhos/cm
pH	24	8.2	7.7-8.7	units
Temperature	24	9.0	0.0-22.0	deg. C
Turbidity	17	10	1-40	JTU
Dissolved oxygen	24	95	87-107	percent
Biochemical oxygen demand	24	1.9	.1-8.0	mg/L
Calcium (Ca), dissolved	22	60	30-86	mg/L
Magnesium (Mg), dissolved	24	42	13-73	mg/L
Sodium (Na), dissolved	22	41	14-110	mg/L
Percent sodium	22	21	17-32	percent
Sodium-adsorption ratio	22	1.0	.0-2.2	---
Potassium (K), dissolved	22	4.4	1.7-7.3	mg/L
Bicarbonate (HCO_3)	23	251	122-376	mg/L
Carbonate (CO_3)	20	1	0-10	mg/L
Sulfate (SO_4), dissolved	22	190	47-420	mg/L
Chloride (Cl), dissolved	22	3.6	1.2-7.2	mg/L
Fluoride (F), dissolved	22	.3	.2-.5	mg/L
Silica (SiO_2), dissolved	22	4.6	.5-7.7	mg/L
Dissolved solids (calculated)	22	468	176-896	mg/L
Nitrite plus nitrate, total as N	21	.10	.00-.75	mg/L
Nitrogen, ammonia, total as N	21	.03	.00-.13	mg/L
Nitrogen, total organic as N	21	.59	.26-2.4	mg/L
Nitrogen, total kjeldahl as N	21	.62	.27-2.5	mg/L
Phosphorus, total as P	21	.07	.00-.38	mg/L
Suspended sediment	17	58	2-292	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	7	0-120	8	60-600	ug/L
Arsenic	7	0-2	5	0-2	ug/L
Beryllium	7	0-10	5	0-10	ug/L
Boron	20	10-150	---	---	ug/L
Cadmium	7	0-1	5	<10-10	ug/L
Chromium	7	0-10	5	0-10	ug/L
Copper	8	2-4	8	0-20	ug/L
Iron	24	0-260	5	20-1400	ug/L
Lead	8	0-7	8	<100	ug/L
Lithium	5	10-30	5	10-40	ug/L
Manganese	12	0-120	5	10-80	ug/L
Mercury	6	.0-.1	8	.0-.3	ug/L
Molybdenum	5	0-2	5	0-2	ug/L
Nickel	7	0-6	5	<50	ug/L
Selenium	8	0-1	8	0-1	ug/L
Vanadium	7	.5-9.0	---	---	ug/L
Zinc	8	0-1900	8	10-280	ug/L

Figure 22.--Continued

Water temperatures were 0°C during much of the winter and ice cover was common. Dissolved oxygen most often ranged from 90 to 100 percent of saturation, but had low and high values of 87 and 107 percent, respectively. Water pH showed slight increases over those measured below the dam, with the highest measured value being 8.7.

The nutrients and trace elements had values and patterns that were little changed from those at the upstream station, Tongue River at Tongue River Dam. Likewise, the water-quality conditions that dictate water uses remained much the same. Water entering from Hanging Woman Creek upstream was of much inferior quality; however, the quantity was small and little effect was noted after mixing in the river.

Results of sampling at this station show that the Tongue River Dam continues to be the major control for suspended sediment. During the winter period, concentrations were generally less than 20 mg/L--often a slight reduction when compared to the station below the dam. Sediment contribution between the dam and this station occurred at times of surface runoff when intermittent streams were flowing and when Hanging Woman Creek was carrying heavy sediment loads. In addition, sediment concentrations increased at the station when high flows resulted from release at the dam--an indication that channel scouring and lateral erosion occur at higher flows. This condition on July 9, 1975, with a sediment concentration of 143 mg/L and a discharge of 3,500 ft^3/s, represented the highest calculated suspended-sediment load of 1,350 tons/day (fig. 22).

Otter Creek at Ashland

Otter Creek at Ashland was sampled at the gaging station (station 13) 2.5 miles upstream from the mouth and just upstream from the town of Ashland. The stream bottom is stable and composed of gravel and finer sediment with periphyton observed during much of the year. The drainage area upstream from the station is 707 mi^2. About 4,200 acres of the drainage is irrigated--mostly by water spreading.

The streamflow hydrograph for the 1975 water year is shown in figure 23. Like Hanging Woman Creek, base flows were near 1 ft^3/s, but because of the larger drainage area of Otter Creek, surface runoff and contribution of alluvial aquifers caused higher streamflow during other parts of the year. Surface runoff is controlled to some degree by the numerous stock pond dams in the upper drainage.

With the exception of high runoff periods, the water was a sodium sulfate type (fig. 24) and similar in nature to most other small perennial streams draining the Fort Union Formation. Sodium accounted for about 50 percent of the cation ratio and sulfate from 60 to 70 percent of the anions. As streamflow increased owing to surface runoff, calcium percentages approached those of sodium, and bicarbonate dominated sulfate. Magnesium at all flow conditions was consistently near 35 percent of the cations.

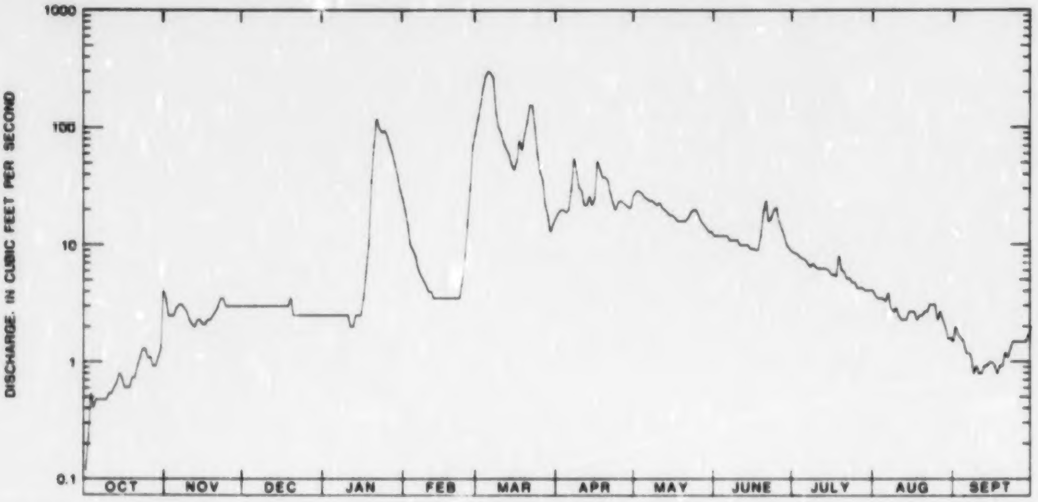


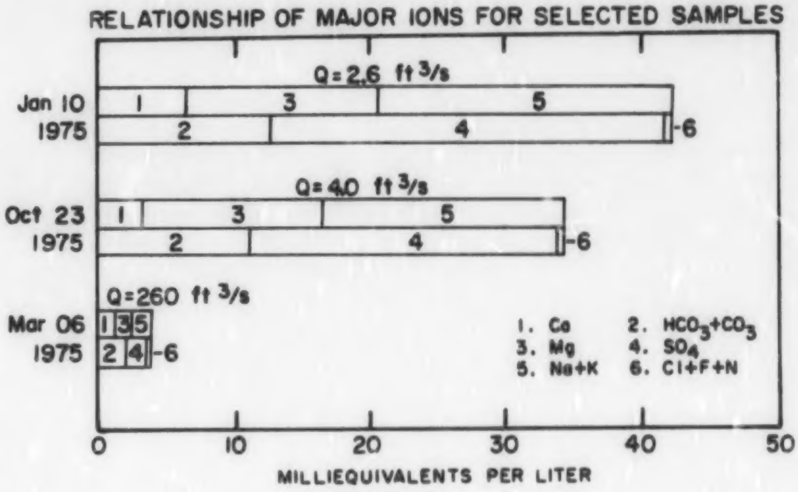
Figure 23.--Hydrograph of stream discharge for Otter Creek at Ashland, 1975 water year.

Dissolved-solids concentrations throughout the late spring, summer, and fall were seldom measured below 2,000 mg/L. Lower concentrations were coincidental with snowmelt and storms at times in the winter and early spring. The lowest measured dissolved-solids concentration occurred March 6, 1975, but because of a high discharge, it represented the highest calculated load. A concentration of 228 mg/L and a discharge of 287 ft^3/s combined to give a dissolved-solids load of 177 tons/day.

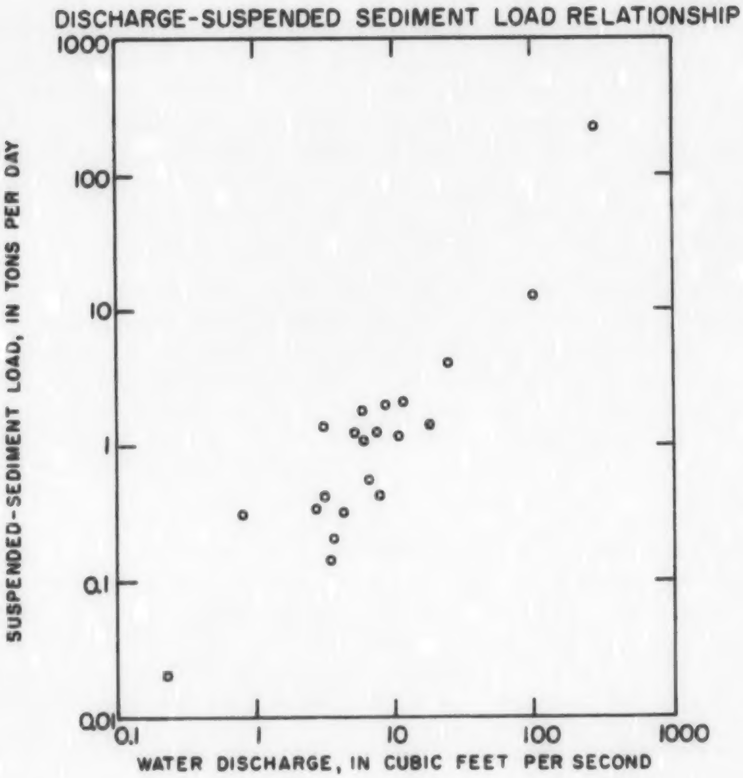
Dissolved oxygen ranged from 37 to 112 percent of saturation. The two extreme measurements were made in the summer--the lower in early morning and the higher in late afternoon; together they suggest a summer diel cycle. When measured from the highest sampled flow, the pH had its lowest value of 7.2. On three occasions, all during periods of low flow, the maximum pH of 8.6 was recorded. Turbidity ranged from 6 to 100 JTU's (Jackson turbidity units)--not a large variation when compared to the other small perennial streams in the study area.

The nitrogen constituents generally had increased concentrations during the winter. This was especially true of ammonia and may have resulted from the decomposition of organic material under the ice. Total phosphorus was high (0.68 mg/L) on the March 6, 1975, sample when the sediment concentration was at its maximum. BOD concentrations commonly ranged from 1 to 2 mg/L. The maximum value of 9.3 mg/L occurred during the winter runoff on January 22, 1975.

The total trace elements had comparatively low concentrations that reflected the small amount of sediment in the stream at times of sample collection. Total copper had a moderate concentration of 110 μg/L on December 19, 1974, and total chromium had a concentration of 90 μg/L on October 23, 1975. Of the dissolved trace elements, only zinc had a significant value of 110 μg/L on December 19, 1974.



RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 24.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Otter Creek at Ashland (station 13).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	25		0.19-287	ft^3/s
Specific conductance (at 25 deg. C)	25	2690	370-3900	umhos/cm
pH	25	8.2	7.2-8.6	units
Temperature	25	8.5	0.0-24.5	deg. C
Turbidity	25	25	6-100	JTU
Dissolved oxygen	25	86	37-112	percent
Biochemical oxygen demand	25	2.2	.0-9.3	mg/L
Calcium (Ca), dissolved	25	80	23-120	mg/L
Magnesium (Mg), dissolved	25	150	15-190	mg/L
Sodium (Na), dissolved	25	340	26-460	mg/L
Percent sodium	25	46	29-52	percent
Sodium-adsorption ratio	25	5.1	1.0-6.5	---
Potassium (K), dissolved	25	18	8.1-27	mg/L
Bicarbonate (HCO_3)	25	574	110-810	mg/L
Carbonate (CO_3)	25	7	0-58	mg/L
Sulfate (SO_4), dissolved	25	1100	80-1500	mg/L
Chloride (Cl), dissolved	25	11	1.3-16	mg/L
Fluoride (F), dissolved	25	.7	.1-.9	mg/L
Silica (SiO_2), dissolved	25	8.8	2.1-17	mg/L
Dissolved solids (calculated)	25	1970	228-2690	mg/L
Nitrite plus nitrate, total as N	25	.22	.00-.71	mg/L
Nitrogen, ammonia, total as N	24	.07	.00-.28	mg/L
Nitrogen, total organic as N	24	1.0	.38-3.9	mg/L
Nitrogen, total kjeldahl as N	24	1.1	.49-3.9	mg/L
Phosphorus, total as P	25	.08	.00-.68	mg/L
Suspended sediment	25	76	19-299	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0	6	160-780	ug/L
Arsenic	2	1	11	0-4	ug/L
Beryllium	2	<10-10	10	0-10	ug/L
Boron	25	120-590	---	---	ug/L
Cadmium	2	1-<50	11	<10-10	ug/L
Chromium	2	0-<10	11	0-90	ug/L
Copper	2	2-10	11	0-110	ug/L
Iron	25	10-490	11	280-2900	ug/L
Lead	2	1-<14	11	<100-100	ug/L
Lithium	2	130-150	11	20-150	ug/L
Manganese	2	20-30	11	50-360	ug/L
Mercury	2	.0-<.1	11	.0-.8	ug/L
Molybdenum	2	4-<6	11	1-9	ug/L
Nickel	2	3-<14	11	0-50	ug/L
Selenium	1	1	11	0-3	ug/L
Vanadium	2	.8-<10	---	---	ug/L
Zinc	2	10-110	6	10-40	ug/L

Figure 24.--Continued

The major uses of water from Otter Creek are for irrigation and stock watering. The quality for irrigation shows a high salinity hazard and a medium sodium hazard (fig. 2). Only by growing the more salt-tolerant crops and by using sufficient water for leaching purposes is the water suitable for irrigation. However, water captured from snowmelt or storms would be of good irrigation quality. Stream water is of suitable quality for all types of stock.

Suspended-sediment concentrations were highest during spring storms and throughout the summer months. The highest measured concentration was 299 mg/L on March 6, 1975, and represented a calculated suspended-sediment load of 232 tons/day being discharged into the Tongue River (fig. 24).

Tongue River below Brandenberg Bridge near Ashland

In addition to being a monthly water-quality sampling site, Tongue River below Brandenberg Bridge near Ashland (station 14) was also a daily suspended-sediment station and a continuous-recording streamflow station. All sampling was done from the Brandenberg Bridge, which is 6.5 miles upstream from the gaging station. The channel throughout this reach of stream is composed of gravel, sand, and silt and is subject to some shifting. The station is less than 2 miles downstream from the contact between the Tongue River and Lebo Shale Members of the Fort Union Formation. Shrubs and trees are dense along the banks.

Streamflow continued to be influenced largely by the Tongue River Dam, although storm runoff and snowmelt between the dam and station and irrigation practices had some effect (fig. 25). The lowest flow sampled was 83 ft^3/s during the period of dam closure on November 12, 1975. Generally, the flows sampled during the 1975 water year were higher than during the 1976 water year. About 58,000 acres is irrigated between the dam and this station.

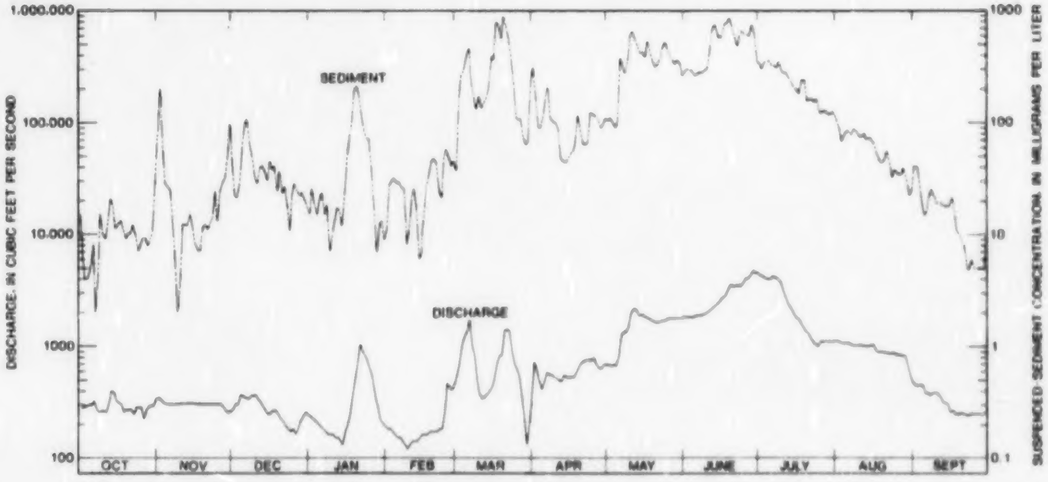


Figure 25.--Hydrographs of stream discharge and suspended-sediment concentration for Tongue River below Brandenberg Bridge near Ashland, 1975 water year.

Water types at all flows were slightly more diverse than water sampled at the upstream stations (fig. 26) owing to the additional surface and subsurface inflows. Water from base-flow conditions, during normal release patterns at the dam, showed magnesium to be dominant in the cation ratio followed by calcium and sodium. For the anion ratio, sulfate was generally slightly greater than bicarbonate. When spring runoff provided its greatest contribution to streamflow, the water contained principally calcium, magnesium, and bicarbonate.

Like water type, the dissolved-solids concentrations showed greater variations at this station than found upstream, and ranged from 203 to 868 mg/L. The maximum value, however, occurred on November 11, 1975, when the outflow structure of the dam was closed. A concentration of 698 mg/L on December 18, 1975, was the maximum recorded concentration during normal operation of the dam. The highest calculated load was 2,560 tons/day on May 23, 1975, from a dissolved-solids concentration of 564 mg/L and a discharge of 1,680 ft^3/s.

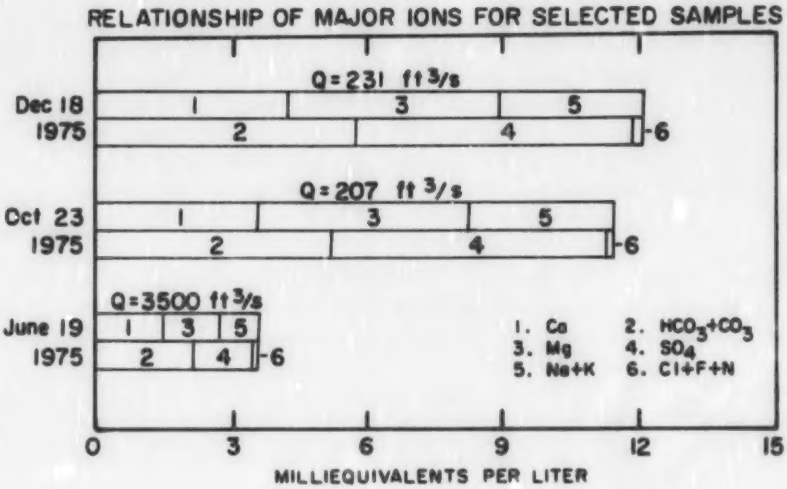
Daily measurements showed the water temperature to be consistently near 25°C throughout much of July and August. During the 1975 water year the maximum and minimum measured temperatures were 27.0°C and 0.0°C--complete ice cover was present during much of the winter. Dissolved oxygen was often near 100 percent of saturation, but seldom exceeded that value. During the periods of ice cover some oxygen deficiency was generally noted with the lowest measured value of 61 percent on February 20, 1975. Water pH had ranges much the same as measured upstream; the minimum values were associated with water contributed by runoff and the maximums with base-flow contributions.

Total nitrogen and phosphorus concentrations, although similar in range to upstream measurements, had a better correlation to suspended sediment. The BOD had maximum values during periods of high surface runoff but was near average or below when flow was solely a result of release from the dam.

Higher concentrations for some of the total trace elements, as listed in figure 26, were due mostly to suspended sediment. During the peak sediment concentration sampled on June 19, 1975, total iron was 13,000 µg/L and total aluminum 6,000 µg/L. The dissolved minor elements changed little in value from those sampled upstream.

Within the Tongue River drainage study area, this was the only daily suspended-sediment station. The 1975 water year mean daily concentration hydrograph is shown with the discharge hydrograph (fig. 25). Figure 26 represents only those suspended-sediment loads that correspond in time to the chemical samples. More complete daily suspended-sediment data can be found in annual reports (U.S. Geological Survey, issued annually).

The hydrograph shows that suspended-sediment concentrations generally followed streamflow, although the first 7 months is more erratic than the rest of the year. The difference can be related to the sediment sources that were available during the year. From early winter until high-mountain runoff began in May, release from the dam was low and constant--the fluctuations were a result of surface inflow downstream from the dam due to snowmelt and



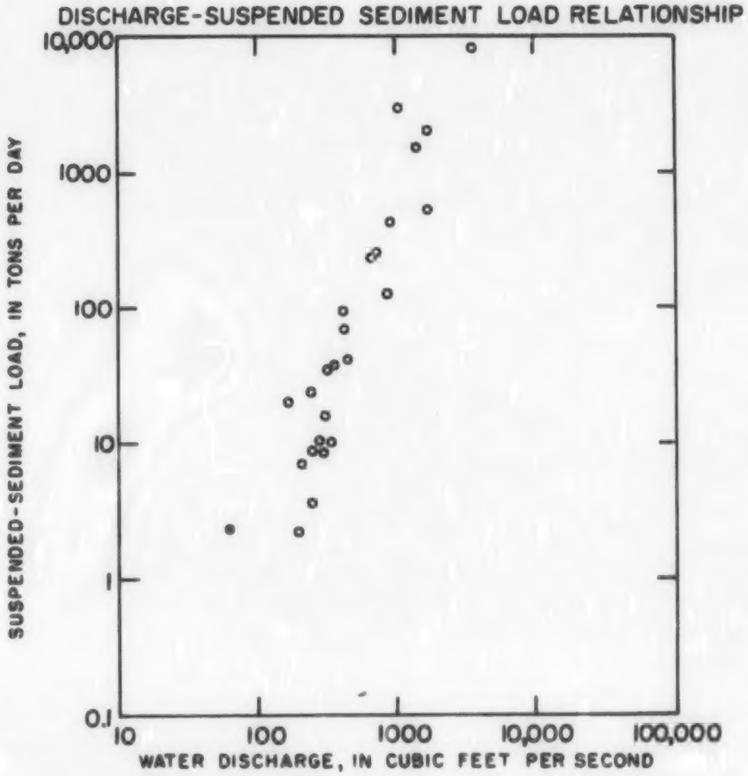


Figure 26.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Tongue River below Brandenberg Bridge near Ashlan (station 14).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	26		83-3500	ft^3/s
Specific conductance (at 25 deg. C)	25	802	350-1300	umhos/cm
pH	25	8.1	7.3-8.4	units
Temperature	26	9.5	0.0-23.0	deg. C
Turbidity	24	10	1-200	JTU
Dissolved oxygen	25	92	61-104	percent
Biochemical oxygen demand	24	1.9	.4-7.8	mg/L
Calcium (Ca), dissolved	24	61	27-88	mg/L
Magnesium (Mg), dissolved	24	42	15-62	mg/L
Sodium (Na), dissolved	24	50	17-110	mg/L
Percent sodium	24	24	19-33	percent
Sodium-adsorption ratio	24	1.2	.6-2.2	---
Potassium (K), dissolved	24	4.7	2.0-8.3	mg/L
Bicarbonate (HCO_3)	24	262	124-397	mg/L
Carbonate (CO_3)	24	1	0-10	mg/L
Sulfate (SO_4), dissolved	24	214	63-390	mg/L
Chloride (Cl), dissolved	24	4.1	1.4-6.1	mg/L
Fluoride (F), dissolved	24	.3	.2-.4	mg/L
Silica (SiO_2), dissolved	24	5.5	1.1-9.3	mg/L
Dissolved solids (calculated)	24	512	203-868	mg/L
Nitrite plus nitrate, total as N	24	.05	.00-.14	mg/L
Nitrogen, ammonia, total as N	23	.03	.00-.20	mg/L
Nitrogen, total organic as N	22	.60	.25-1.7	mg/L
Nitrogen, total kjeldahl as N	23	.60	.07-1.9	mg/L
Phosphorus, total as P	24	.06	.00-.30	mg/L
Suspended sediment	25	---	4-1000	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-30	7	80-6000	ug/L
Arsenic	2	0-1	10	0-4	ug/L
Beryllium	2	<10-10	9	0-10	ug/L
Boron	24	20-170	---	---	ug/L
Cadmium	2	0-2	10	0-10	ug/L
Chromium	2	0-<10	10	0-50	ug/L
Copper	2	1-5	10	0-30	ug/L
Iron	24	0-190	10	110-13000	ug/L
Lead	2	1-2	10	<100-100	ug/L
Lithium	2	30	10	10-30	ug/L
Manganese	2	0-20	9	10-70	ug/L
Mercury	2	<.1-.1	10	.0-.5	ug/L
Molybdenum	2	0-<2	10	0-3	ug/L
Nickel	2	2-8	10	0-50	ug/L
Selenium	1	0	10	0-1	ug/L
Vanadium	2	.5-<3.0	---	---	ug/L
Zinc	2	10-90	7	0-80	ug/L

Figure 26.--Continued

storms. The periodic surface inflows carried with them high amounts of sediment and produced additional sediment through channel scour. From May through August, larger quantities of water were released from the dam, but surface inflow between the dam and this station was small. The single sediment source during this part of the year was from channel scour. The result is that many of the sharp sediment peaks do not occur during this period.

Tongue River at Miles City

Samples were collected at the gaging station (station 15) 8 miles upstream from the mouth. Small gravel, sand, and silt form the unstable bottom; dune formation was evident in parts of the channel. Fluvially deposited fine coal sediment was noticed on the streambed in some of the backwaters. Water coloration was generally a result of suspended sediment; however, at times visible phytoplankton affected the color. The steep banks, throughout the stream section, are several feet high and subject to sloughing when lateral movement of the river occurs.

The 1975-water-year hydrograph for this station (fig. 27) differs only slightly from the hydrograph for the station below Brandenberg Bridge. Winter and spring runoff peaks were often higher and always broader at this station, and summer flows were somewhat reduced as a result of irrigation practices. Evidence from the November 1975 low-flow study of R. D. Hutchinson and A. J. Boettcher (written commun., 1976) indicates that the channel between the two stations is a gaining section. This part of the channel transects predominantly the Tullock Member of the Fort Union Formation. During normal operation of the Tongue River Dam, the maximum and minimum flows sampled were 4,140 and 140 ft^3/s, respectively.

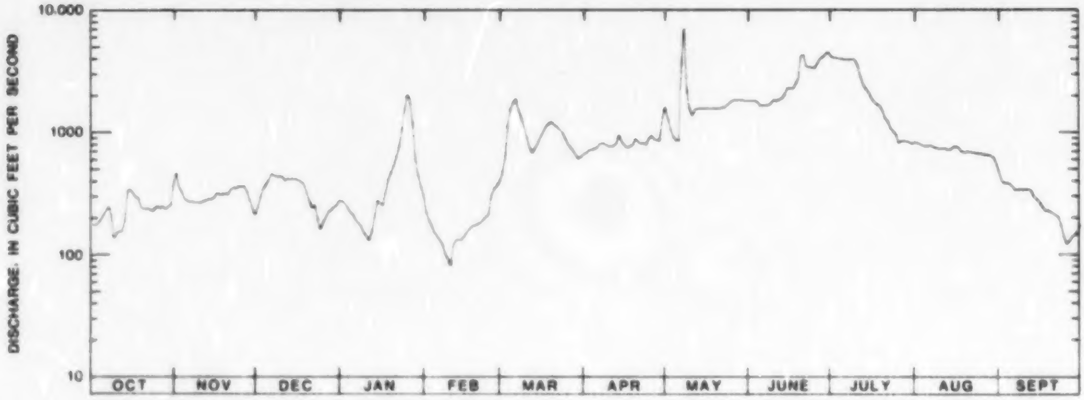


Figure 27.--Hydrograph of stream discharge for Tongue River at Miles City, 1975 water year.

Water types were erratic and correlated poorly with either dissolved-solids concentrations or streamflow (fig. 28). Sodium percentages ranged from 23 to 49 percent--the greater percentage sometimes occurring at periods of high flow. Although difficult to verify without more intensive sampling, high flows from Pumpkin Creek of water high in sodium apparently were partly responsible for this anomalous condition. The calcium and magnesium cations also had similar percentage changes during the period. The bicarbonate anion followed the trends of calcium and the sulfate anion the trends of sodium.

Dissolved-solids concentrations ranged from 281 to 912 mg/L. The maximum concentrations occurred during the dam closure. The mean concentration for the period was 563 mg/L, about a 10-percent increase when compared with the Brandenberg station and a 25-percent increase compared with the outflow at Tongue River Dam. The increases were primarily due to ground-water inflow, parts of which were irrigation returns that had been altered by evaporation and transpiration. Once-daily conductance measurements at the station show that abrupt changes in dissolved solids occur at times during the annual streamflow cycle--probably owing to release practices at the dam and surface runoff between the dam and the station. The maximum computed dissolved-solids load was 2,560 tons/day on May 23, 1975.

The average nutrient concentrations were the highest of all Tongue River stations and reflect the increase in suspended sediment. Direct correlation between nutrients (total nitrogen and total phosphorus) and suspended sediment was good and even better when compared to the percent of suspended sediment finer than 0.062 millimeter. Total nitrogen had its maximum value of 3.1 mg/L on June 19, 1975, when sampled at the highest flow and the maximum suspended-sediment concentration. Total phosphorus, sampled at the same time, had a maximum concentration of 1.0 mg/L.

Like nutrients, many of the total minor elements analyzed from the Tongue River had their highest concentrations at this station and similarly were associated with high suspended-sediment concentrations. From the June 19, 1975, sample, the maximum values as listed in figure 28 were measured for total arsenic, total chromium, total copper, total iron, total selenium, and total zinc. The dissolved minor elements were little changed from upstream values. Only copper had a slightly higher concentration.

Although dissolved-solids concentrations increased at this station and higher percentages of sodium were more prevalent, the changes were not significant enough to affect water uses for irrigation. The June, July, and August samples for the 2 years had a mean dissolved-solids concentration of 340 mg/L and SAR values of 1 to 2. The water, when classified for irrigation, had a medium salinity hazard and a low sodium hazard. The most severe quality problem results from high concentrations of suspended sediment during parts of the irrigation season.

The stream channel between the Brandenberg station and this site provides a source of sediment that becomes readily available when streamflows exceed 500 ft^3/s. The maximum sediment concentration was 4,360 mg/L on June 19, 1975, and represented a suspended-sediment load of 48,700 tons/day (fig. 28). More

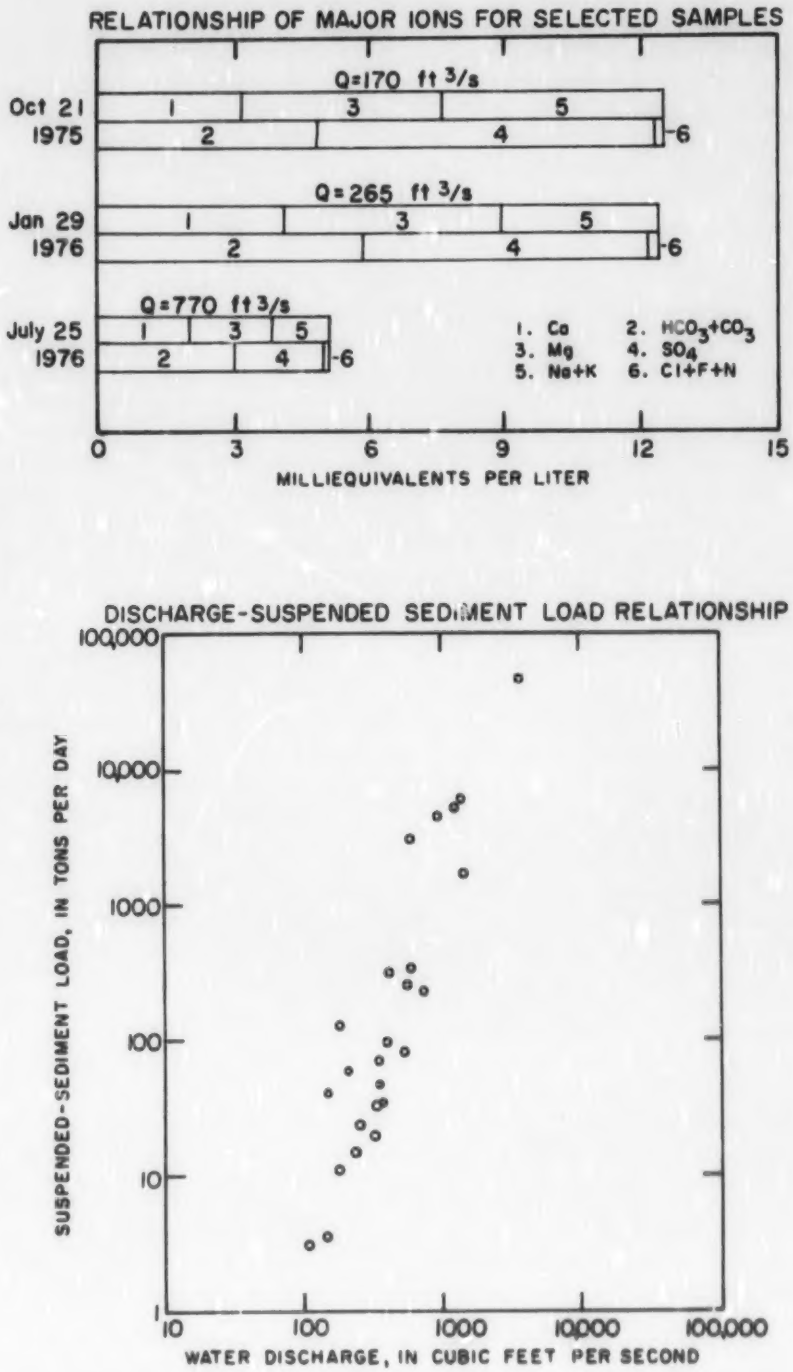


Figure 28.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Tongue River at Miles City (station 15).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	25		106-4140	ft^3/s
Specific conductance (at 25 deg. C)	25	838	440-1320	umhos/cm
pH	25	8.3	7.7-8.5	units
Temperature	25	9.5	0.0-27.0	deg. C
Turbidity	25	160	1-1200	JTU
Dissolved oxygen	25	97	79-110	percent
Biochemical oxygen demand	7	2.3	.8-5.5	mg/L
Calcium (Ca), dissolved	25	61	27-83	mg/L
Magnesium (Mg), dissolved	25	43	14-61	mg/L
Sodium (Na), dissolved	25	67	29-130	mg/L
Percent sodium	25	30	23-49	percent
Sodium-adsorption ratio	25	1.6	.9-3.0	---
Potassium (K), dissolved	25	4.8	2.9-6.7	mg/L
Bicarbonate (HCO_3)	25	276	142-369	mg/L
Carbonate (CO_3)	23	1	0-5	mg/L
Sulfate (SO_4), dissolved	25	240	89-440	mg/L
Chloride (Cl), dissolved	25	4.4	1.8-8.7	mg/L
Fluoride (F), dissolved	25	.3	.2-.5	mg/L
Silica (SiO_2), dissolved	25	5.4	.5-8.9	mg/L
Dissolved solids (calculated)	25	563	281-912	mg/L
Nitrite plus nitrate, total as N	25	.08	.00-.32	mg/L
Nitrogen, ammonia, total as N	1	.00	.00	mg/L
Nitrogen, total organic as N	1	.73	.73	mg/L
Nitrogen, total kjeldahl as N	25	.84	.19-2.9	mg/L
Phosphorus, total as P	25	.2	.00-1.0	mg/L
Suspended sediment	25	541	9-4360	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	20	1	350	ug/L
Arsenic	9	0-1	8	0-26	ug/L
Beryllium	1	10	1	10	ug/L
Boron	1	180	---	---	ug/L
Cadmium	9	0-1	9	0-20	ug/L
Chromium	9	0-10	9	0-80	ug/L
Copper	9	1-7	9	<10-170	ug/L
Iron	9	0-150	9	220-74000	ug/L
Lead	9	1-7	9	0-<100	ug/L
Lithium	1	30	1	20	ug/L
Manganese	9	0-20	8	10-680	ug/L
Mercury	9	.0-.2	9	.0-.2	ug/L
Molybdenum	1	0	1	3	ug/L
Nickel	1	1	1	50	ug/L
Selenium	9	0-1	9	0-2	ug/L
Vanadium	1	.5	---	---	ug/L
Zinc	9	0-20	9	10-340	ug/L

Figure 28.--Continued

than half the samples had concentrations of less than 100 mg/L, and a low concentration of 9 mg/L occurred in September 1975.

Sediment samples from this station were analyzed to determine the percentage of material finer than 0.062 millimeter or the percentage represented as silt and clay. Samples with concentrations in excess of 100 mg/L, collected from high flows, contained percentages of silt and clay in excess of 80 percent. Conversely, samples from lesser flows generally carried coarser material. The condition relates to sediment sources in which overland runoff at times of high flow makes sediment fines available to the stream. Diminishing flows flush much of the fine sediment from the channel and at reduced flows only coarser material is available for transport.

Small tributaries

Streams described in this section are small and mostly intermittent; all flow into the Tongue River or its main tributaries and contribute very little or no water except during periods of high surface runoff. Small stockpond impoundments upstream from most stations had varying influence on streamflow at the sampling site.

Of the 10 streams, 4 had water only during times of surface runoff and shortly thereafter the streambeds were dry. The samples analyzed from these streams for dissolved constituents had low concentrations--a reflection of the composition of rainfall and freshly melted snow. Because of the intensity of surface runoff, organic and inorganic particles from the surface were picked up and carried in suspension. Analyses of constituents from the water-sediment mixture, conversely, often had high concentrations.

Four of the streams had flows during surface-runoff periods and, in addition, continued to flow for longer periods. The extended flow was due to surface water infiltrating and recharging alluvial aquifers during periods of high flow. The aquifers then contributed the water back to the streams as the high flow began to recede. As water from the aquifers was depleted, streamflow diminished and ceased. During periods of runoff, the water quality was similar to that described above. During the extended flows, however, the water had longer contact with consolidated and unconsolidated materials and thus the concentrations of many of the dissolved constituents was much greater. These four streams were more subject to ponding at low discharges--a condition that caused even higher concentrations of dissolved solids, owing to evaporation and transpiration from increased surface area and heavy aquatic vegetation that occupied the pools.

The remaining two streams at the sampling sites were perennial. Base flow was often significant enough to influence the quality of surface inflow water by elevating the dissolved-solids concentrations. Maximum dissolved-solids concentrations were much less than found at the four upstream stations --the condition, at least in part, a result of reduced ponding.

Squirrel Creek near Decker

Squirrel Creek is perennial and the largest of the streams discussed in this section. Samples were collected at the gaging station (station 16) 7 miles upstream from the mouth. Both the stream-gaging and water-quality programs were started at the beginning of the 1976 water year.

The channel near the station is relatively stable, and is composed of gravel, sand, and silt. Periphyton was observed on the bottom during most of the year. Although ponding is common in downstream sections, flow near the sampling site is relatively unimpeded. Twelve samples were collected from flows ranging from 0.27 to 10 ft^3/s.

The water was a magnesium bicarbonate type for all samples; sodium never exceeded 15 percent of the cations and sulfate was always less than 50 percent of the anions (fig. 29). The dissolved-solids concentrations were relatively low and had a narrow range of 605 to 866 mg/L. The water type, the consistency in water type, and the limited range in dissolved-solids concentration are all atypical of the smaller streams in the study area, and may have been largely affected by local ground-water contribution.

The higher percentages of magnesium and calcium result in a water that is very hard. The lack of sodium and only moderate amounts of dissolved solids make the water of good quality for irrigation.

Correlation between suspended-sediment concentration and discharge was poor. The highest suspended-sediment concentration was measured at a medium flow and the lowest discharge had the fourth highest sediment concentration. The largest calculated suspended-sediment load was 4.8 tons/day (fig. 29).

Deer Creek near Decker

The sampling site (station 17) is located 6.1 miles upstream from the mouth in the mid-part of the drainage. The stream gradient in this section is small and ponding is common--even in late summer when surface flow is absent. Subsurface discharge is sufficient to maintain the pools throughout the year.

Water samples were collected only at times when flow was obvious between pools. Nine samples were collected over 2 years from measured flows ranging from 0.06 to 9.1 ft^3/s. Higher flows may have occurred during the period; however, the maximum flow sampled was on January 21, 1975--the same day that many of the smaller streams in the study area peaked. Presumably, the many small stock impoundments in the upper Deer Creek drainage significantly reduce any runoff.

Except for the three higher flows sampled, the water contained principally sodium, magnesium, and sulfate and ranged in dissolved-solids concentration from 3,560 to 4,950 mg/L (fig. 30). The three higher flows were from surface runoff and resulted in dissolved-solids concentration ranging from 268 to 1,110 mg/L and a water type that consisted of increased percentages of calcium and bicarbonate.

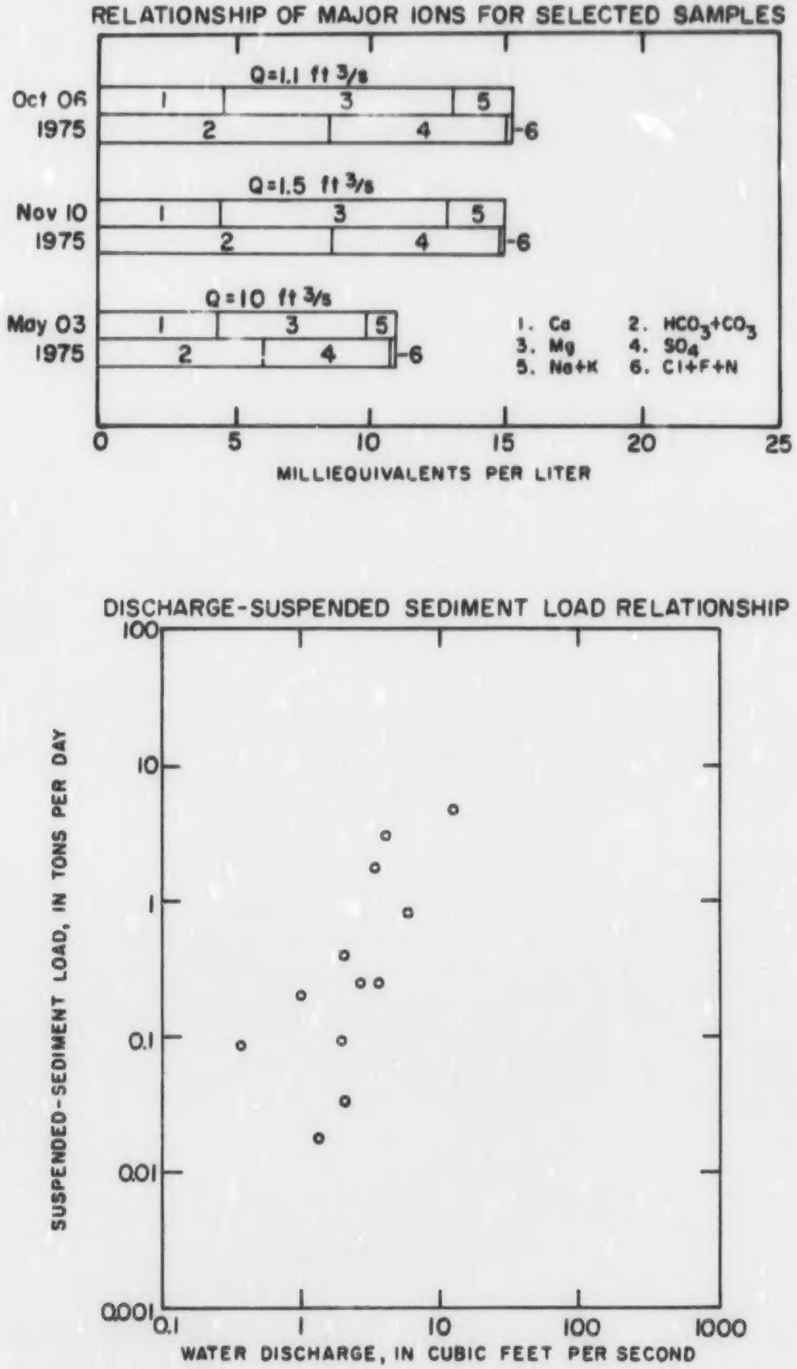
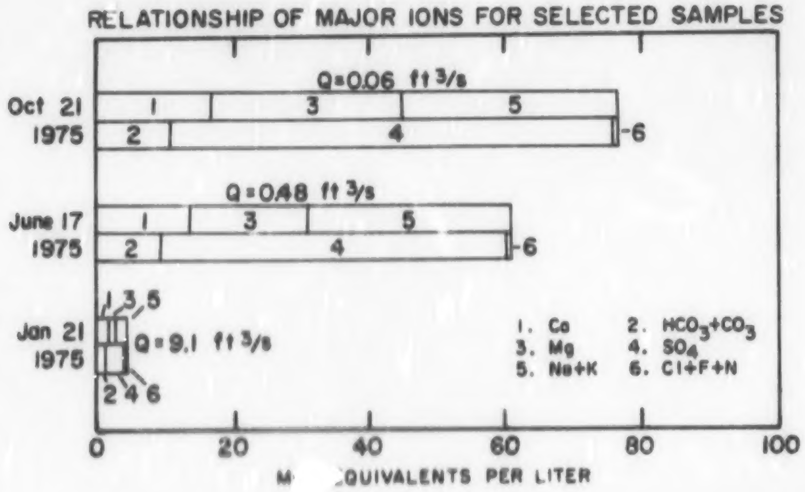


Figure 29.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Squirrel Creek near Decker (station 16).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	12		0.27-10	ft^3/s
Specific conductance (at 25 deg. C)	12	1110	915-1340	umhos/cm
pH	12	8.1	7.9-8.5	units
Temperature	12	8.5	0.0-19.0	deg. C
Turbidity	12	20	2-100	JTU
Dissolved oxygen	12	94	79-114	percent
Biochemical oxygen demand	12	1.3	.2-4.2	mg/L
Calcium (Ca), dissolved	12	83	67-100	mg/L
Magnesium (Mg), dissolved	12	86	66-100	mg/L
Sodium (Na), dissolved	12	37	22-49	mg/L
Percent sodium	12	12	9-15	percent
Sodium-adsorption ratio	12	.7	.4-.9	---
Potassium (K), dissolved	12	6.9	5.1-10	mg/L
Bicarbonate (HCO_3)	12	449	371-557	mg/L
Carbonate (CO_3)	12	2	0-13	mg/L
Sulfate (SO_4), dissolved	12	270	220-320	mg/L
Chloride (Cl), dissolved	12	3.7	1.6-7.4	mg/L
Fluoride (F), dissolved	12	.4	.2-.5	mg/L
Silica (SiO_2), dissolved	12	11	5.3-14	mg/L
Dissolved solids (calculated)	12	723	605-866	mg/L
Nitrite plus nitrate, total as N	12	.20	.00-.57	mg/L
Nitrogen, ammonia, total as N	12	.02	.00-.04	mg/L
Nitrogen, total organic as N	12	.48	.18-.97	mg/L
Nitrogen, total kjeldahl as N	12	.50	.22-.97	mg/L
Phosphorus, total as P	12	.07	.00-.13	mg/L
Suspended sediment	12	90	6-303	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	0	5	20-730	ug/L
Arsenic	1	1	5	0-2	ug/L
Beryllium	1	10	5	0-10	ug/L
Boron	12	60-140	---	---	ug/L
Cadmium	1	0	5	0-10	ug/L
Chromium	1	2	5	0-66	ug/L
Copper	1	2	5	0- 10	ug/L
Iron	12	10-180	5	360-2500	ug/L
Lead	1	0	5	100-100	ug/L
Lithium	1	60	5	50-70	ug/L
Manganese	1	110	5	60-130	ug/L
Mercury	1	.0	5	.0-.2	ug/L
Molybdenum	1	3	5	1-2	ug/L
Nickel	1	2	5	50	ug/L
Selenium	1	1	5	0-1	ug/L
Vanadium	1	.8	---	---	ug/L
Zinc	1	20	5	0-20	ug/L

Figure 29.--Continued.



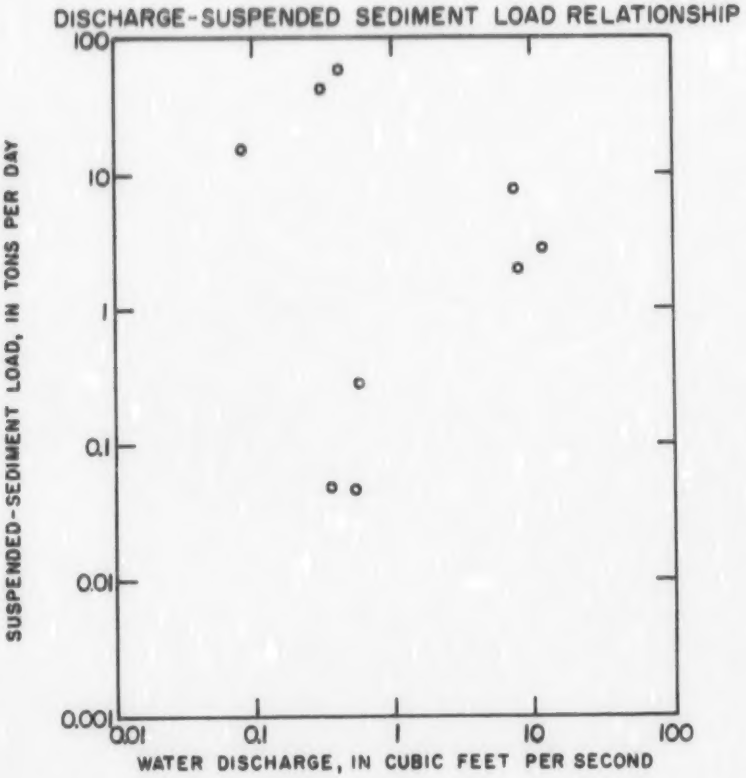


Figure 30.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Deer Creek near Decker (station 17).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	9		0.06-9.1	ft^3/s
Specific conductance (at 25 deg. C)	9	3840	450-6250	umhos/cm
pH	9	8.0	7.4-8.4	units
Temperature	9	6.5	0.0-14.0	deg. C
Turbidity	9	67	2-400	JTU
Dissolved oxygen	9	91	49-129	percent
Biochemical oxygen demand	9	5.1	.6-20	mg/L
Calcium (Ca), dissolved	9	210	32-320	mg/L
Magnesium (Mg), dissolved	9	194	14-340	mg/L
Sodium (Na), dissolved	9	480	30-720	mg/L
Percent sodium	9	41	31-48	percent
Sodium-adsorption ratio	9	5.2	1.1-7.4	---
Potassium (K), dissolved	9	13	7.9-16	mg/L
Bicarbonate (HCO_3)	9	449	86-638	mg/L
Carbonate (CO_3)	9	0	0	mg/L
Sulfate (SO_4), dissolved	9	1910	130-3200	mg/L
Chloride (Cl), dissolved	9	14	4.2-27	mg/L
Fluoride (F), dissolved	9	.3	.1-.5	mg/L
Silica (SiO_2), dissolved	9	6.8	4.0-11	mg/L
Dissolved solids (calculated)	9	3050	268-4950	mg/L
Nitrite plus nitrate, total as N	9	.14	.00-.57	mg/L
Nitrogen, ammonia, total as N	9	.12	.01-.52	mg/L
Nitrogen, total organic as N	9	1.2	.23-2.7	mg/L
Nitrogen, total kjeldahl as N	9	1.4	.24-3.2	mg/L
Phosphorus, total as P	9	.10	.02-.34	mg/L
Suspended sediment	9	109	13-411	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	3	60-140	ug/L
Arsenic	---	---	4	0-5	ug/L
Beryllium	---	---	4	<10-10	ug/L
Boron	9	100-180	---	---	ug/L
Cadmium	---	---	4	<10-30	ug/L
Chromium	---	---	4	0-60	ug/L
Copper	---	---	4	<10-70	ug/L
Iron	9	10-290	4	220-5000	ug/L
Lead	---	---	4	<100-200	ug/L
Lithium	---	---	4	20-220	ug/L
Manganese	---	---	4	140-850	ug/L
Mercury	---	---	4	.0-.2	ug/L
Molybdenum	---	---	4	0-5	ug/L
Nickel	---	---	4	<50-200	ug/L
Selenium	---	---	4	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	3	30-50	ug/L

Figure 30.--Continued

A BOD concentration of 20 mg/L, one of the highest in the study area, was measured on January 20, 1976. Nutrient concentrations were generally high in comparison with other stations, and noticeably increased during the winter and decreased in the spring. Some of the total minor elements, analyzed from the water-sediment mixture, had concentrations somewhat higher than average for the study area. The range for suspended-sediment concentration was 13 to 411 mg/L. Like water discharge, upstream impoundments caused some reduction in sediment movement.

The water from Deer Creek was usable for livestock during most sampled flows. However, long periods of stagnation in the pools with no recharge from surface flow may make the water unfit for livestock consumption.

Fourmile Creek near Birney

Fourmile Creek was sampled 0.9 mile upstream from the mouth at station 18. The drainage area is 22.3 mi^2, the smallest of all tributaries sampled. The channel, throughout the middle and lower sections, is entrenched a few feet, and the gradient is sufficient to produce good flow velocities.

Only during two visits to the site was flow observed. Samples were collected January 19 and February 28, 1975. Both flows were a combination of snowmelt and rainfall--a condition reflected in the low dissolved-solids concentration.

The January flow occurred when the ground was nearly frozen, thereby limiting the contact between runoff water and unconsolidated soil particles. The result was a calcium bicarbonate type water having a dissolved-solids concentration of 143 mg/L (fig. 31). The February sample was collected after much of the land surface had thawed and water was able to penetrate the soil and leach soluble materials. The February sample had nearly equal percentages of magnesium, sodium, and calcium cations, and sulfate accounted for 67 percent of the anions. Dissolved-solids concentration had increased to 394 mg/L.

The nutrients and BOD concentrations were high but typical of other stations measured during surface-runoff periods. Dissolved copper was above average (9 µg/L) and dissolved zinc was high (60 µg/L) for the study area. Suspended-sediment concentrations were 102 and 39 mg/L, respectively, for the January and February samples. The relatively small sediment concentrations and small discharges suggest the samples were not collected from peak flows.

Bull Creek near Birney

Bull Creek was sampled 0.4 mile upstream from the mouth at station 19 where the channel enters the main valley of the Tongue River. The channel near the sampling site is obvious only because of excessive shrubbery within its confines. Catchments and diversions near the station are used for limited downstream irrigation.

The Bull Creek drainage, although nearly double in area, is similar to that of Fourmile Creek. Because of proximity, the runoff periods of the two drainages were coincidental, but the sampled flows at Bull Creek were larger. Samples were collected January 19 and February 28, 1975, at respective discharges of 14 and 2.0 ft^3/s.

Water from the January sample, collected at a time of mostly frozen ground, was dominated by the calcium cation and the bicarbonate anion (fig. 32). Dissolved-solids concentration had a low value of 102 mg/L. The February sample, with a longer residency in the soil, contained principally magnesium, sodium, and sulfate. The dissolved-solids concentration was 528 mg/L.

Suspended-sediment concentrations were relatively low at 50 and 28 mg/L, respectively. The reduced values were largely due to excessive vegetation in the channel that deterred scouring and to catchment of sediment in upstream impoundments.

Cook Creek near Birney

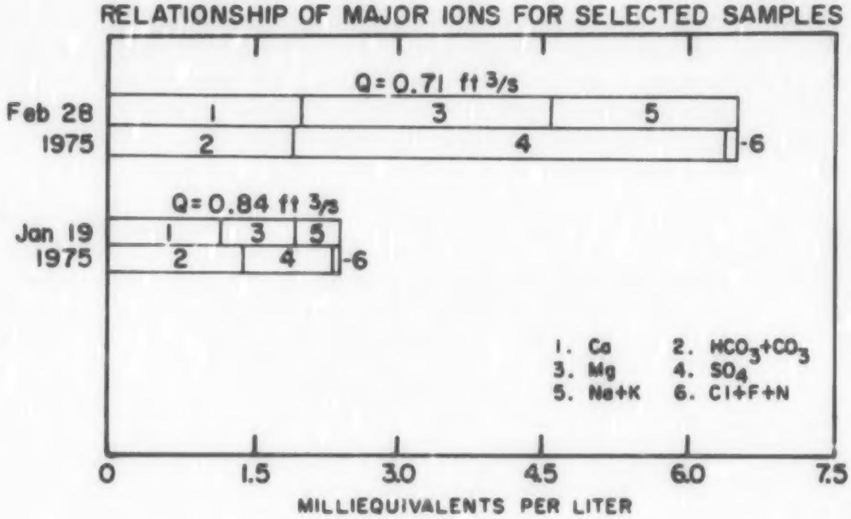
Cook Creek was sampled 0.1 mile upstream from the mouth at station 20. The stream is fed by springs a short distance upstream from the station. Although flow is perennial at the site, often there was no flow upstream from the springs.

Only on two sampling occasions did the discharge exceed 2 ft^3/s. The January 19, 1975, sample was collected at a discharge of 18 ft^3/s--the increased flow a result of snowmelt and rain. The highest sampled flow of 43 ft^3/s on July 8, 1975, was collected after extensive rains.

With the exception of the two high-flow samples, the water was dominated by magnesium, sodium, and sulfate and ranged in dissolved-solids concentration from 911 to 1,470 mg/L (fig. 33). The January 19, 1975, sample, because of the abrupt runoff, had the lowest dissolved-solids concentration of 152 mg/L. Water type also changed at this time, but not extensively. The maximum values for dissolved solids at this station were less than for many of the small perennial streams, and water types from base flow to periods of runoff were less variable; both conditions suggest reduced subsurface influence on the water quality.

Values of total nitrite-nitrate were relatively high during base flow and less during runoff periods. Conversely, total organic nitrogen and total phosphorus were highest on the July 8, 1975, sample and correlated directly with the high sediment concentration at that time.

The high-flow sample of July 8, 1975, provides evidence that at times large amounts of sediment are carried from the drainage area. Using the discharge and the suspended-sediment concentration of 3,470 mg/L, a suspended-sediment load of 403 tons/day was calculated (fig. 33).



SUSPENDED SEDIMENT FOR SELECTED DAYS

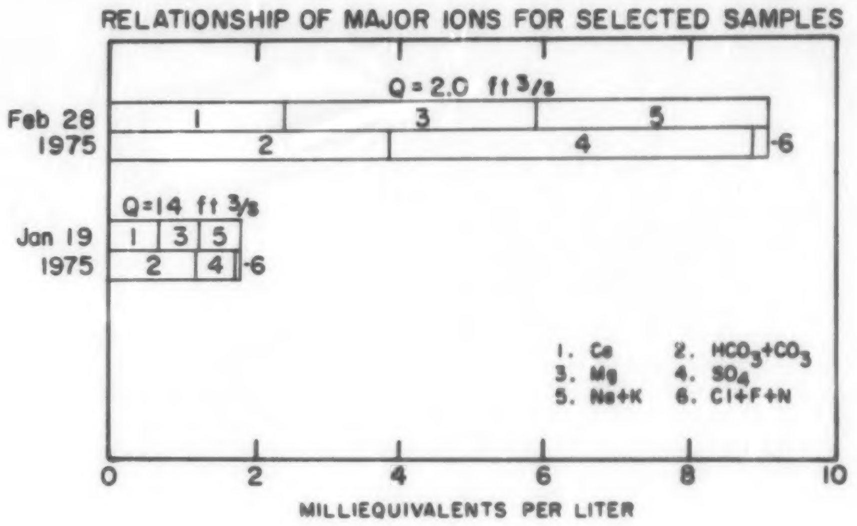
	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1975	Jan. 19	1400	0.0	0.84	102	0.23
	Feb. 28	1415	.0	.71	39	.07

Figure 31.--Relationships of major ions, suspended-sediment, and analytical values for Fourmile Creek near Birney (station 18).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	2		0.71-0.84	ft^3/s
Specific conductance (at 25 deg. C)	2	388	245-530	umhos/cm
pH	2	8.0	7.7-8.2	units
Temperature	2	.0	0.0	deg. C
Turbidity	2	40	40	JTU
Dissolved oxygen	2	89	86-92	percent
Biochemical oxygen demand	2	9.8	7.6-12	mg/L
Calcium (Ca), dissolved	2	32	23-40	mg/L
Magnesium (Mg), dissolved	2	20	9.2-32	mg/L
Sodium (Na), dissolved	2	25	6.5-44	mg/L
Percent sodium	2	20	12-28	percent
Sodium-adsorption ratio	2	.8	.3-1.3	---
Potassium (K), dissolved	2	9.3	7.6-11	mg/L
Bicarbonate (HCO_3)	2	99	86-112	mg/L
Carbonate (CO_3)	2	0	0	mg/L
Sulfate (SO_4), dissolved	2	122	44-200	mg/L
Chloride (Cl), dissolved	2	4.1	2.5-5.6	mg/L
Fluoride (F), dissolved	2	.2	.1-.2	mg/L
Silica (SiO_2), dissolved	2	6.4	5.6-7.1	mg/L
Dissolved solids (calculated)	2	269	143-394	mg/L
Nitrite plus nitrate, total as N	2	.16	.12-.19	mg/L
Nitrogen, ammonia, total as N	2	.05	.03-.06	mg/L
Nitrogen, total organic as N	2	1.3	1.2-1.3	mg/L
Nitrogen, total kjeldahl as N	2	1.3	1.3	mg/L
Phosphorus, total as P	2	.18	.13-.22	mg/L
Suspended sediment	2	71	39-102	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	60	---	---	ug/L
Arsenic	1	4	1	4	ug/L
Beryllium	1	0	1	<10	ug/L
Boron	2	110-190	---	---	ug/L
Cadmium	1	1	1	20	ug/L
Chromium	1	0	1	10	ug/L
Copper	1	9	1	70	ug/L
Iron	2	90-110	1	2700	ug/L
Lead	1	4	1	<100	ug/L
Lithium	---	---	1	10	ug/L
Manganese	1	20	1	70	ug/L
Mercury	1	.1	1	.1	ug/L
Molybdenum	---	---	1	1	ug/L
Nickel	1	2	1	<50	ug/L
Selenium	---	---	1	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	1	60	---	---	ug/L

Figure 31.--Continued.



SUSPENDED SEDIMENT FOR SELECTED DAYS

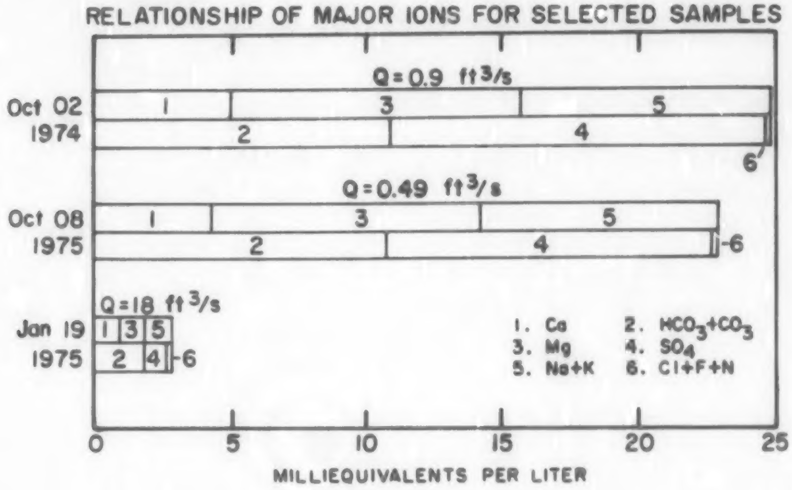
	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1975	Jan. 19	1720	0.0	14	50	1.9
	Feb. 28	1600	.0	2.0	28	.15

Figure 32.--Relationships of major ions, suspended sediment, and analytical values for Bull Creek near Birney (station 19).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	2		2.0-14	ft^3/s
Specific conductance (at 25 deg. C)	2	425	170-680	umhos/cm
pH	2	8.0	7.5-8.4	units
Temperature	2	.0	0.0	deg. C
Turbidity	2	35	30-40	JTU
Dissolved oxygen	2	88	82-94	percent
Biochemical oxygen demand	2	7.0	5.6-8.3	mg/L
Calcium (Ca), dissolved	2	31	13-48	mg/L
Magnesium (Mg), dissolved	2	26	6.7-45	mg/L
Sodium (Na), dissolved	2	40	7.3-72	mg/L
Percent sodium	2	26	19-33	percent
Sodium-adsorption ratio	2	1.1	.4-1.8	---
Potassium (K), dissolved	2	8.7	7.4-9.9	mg/L
Bicarbonate (HCO_3)	2	150	71-220	mg/L
Carbonate (CO_3)	2	0	0	mg/L
Sulfate (SO_4), dissolved	2	130	26-230	mg/L
Chloride (Cl), dissolved	2	3.4	1.7-5.1	mg/L
Fluoride (F), dissolved	2	.2	.1-.3	mg/L
Silica (SiO_2), dissolved	2	6.6	4.7-8.5	mg/L
Dissolved solids (calculated)	2	315	102-528	mg/L
Nitrite plus nitrate, total as N	2	.23	.10-.36	mg/L
Nitrogen, ammonia, total as N	2	.06	.04-.07	mg/L
Nitrogen, total organic as N	2	1.0	.95-1.1	mg/L
Nitrogen, total kjeldahl as N	2	1.1	.99-1.2	mg/L
Phosphorus, total as P	2	.16	.07-.24	mg/L
Suspended sediment	2	1.0	28-50	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	---	---	ug/L
Arsenic	---	---	1	3	ug/L
Beryllium	---	---	1	<10	ug/L
Boron	2	100-190	---	---	ug/L
Cadmium	---	---	1	20	ug/L
Chromium	---	---	1	10	ug/L
Copper	---	---	1	70	ug/L
Iron	2	90	1	1600	ug/L
Lead	---	---	1	100	ug/L
Lithium	---	---	1	0	ug/L
Manganese	---	---	1	60	ug/L
Mercury	---	---	1	.0	ug/L
Molybdenum	---	---	1	0	ug/L
Nickel	---	---	1	<50	ug/L
Selenium	---	---	1	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	---	---	ug/L

Figure 32.--Continued.


RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES

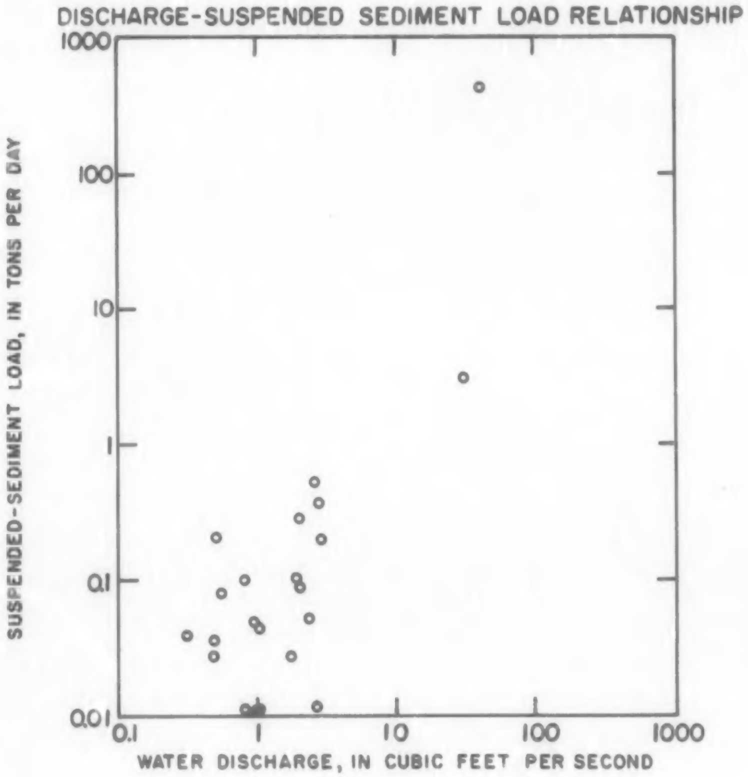

DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 33.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Cook Creek near Birney (station 20).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	22		0.25-43	ft^3/s
Specific conductance (at 25 deg. C)	22	1700	270-2250	umhos/cm
pH	22	8.0	7.7-8.6	units
Temperature	22	7.0	0-19	deg. C
Turbidity	22	120	0-2400	JTU
Dissolved oxygen	22	93	54-117	percent
Biochemical oxygen demand	22	1.8	.2-7.4	mg/L
Calcium (Ca), dissolved	22	78	19-97	mg/L
Magnesium (Mg), dissolved	22	100	11-130	mg/L
Sodium (Na), dissolved	22	170	16-210	mg/L
Percent sodium	22	36	26-40	percent
Sodium-adsorption ratio	22	2.9	.7-3.5	---
Potassium (K), dissolved	22	13	6.6-16	mg/L
Bicarbonate (HCO_3)	22	587	92-709	mg/L
Carbonate (CO_3)	22	1	0-23	mg/L
Sulfate (SO_4), dissolved	22	490	46-670	mg/L
Chloride (Cl), dissolved	22	6.8	2.3-11	mg/L
Fluoride (F), dissolved	22	1.0	.1-1.4	mg/L
Silica (SiO_2), dissolved	22	21	5.6-53	mg/L
Dissolved solids (calculated)	22	1170	152-1470	mg/L
Nitrite plus nitrate, total as N	22	.61	.03-1.7	mg/L
Nitrogen, ammonia, total as N	22	.04	.00-.19	mg/L
Nitrogen, total organic as N	22	.72	.14-3.6	mg/L
Nitrogen, total kjeldahl as N	22	.76	.14-3.6	mg/L
Phosphorus, total as P	22	.11	.00-1.5	mg/L
Suspended sediment	22	189	2-3470	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	2	0-20	6	100-230	ug/L
Arsenic	2	1	11	0-3	ug/L
Beryllium	2	<10-10	11	0-10	ug/L
Boron	22	100-250	---	---	ug/L
Cadmium	2	0-<30	11	0-30	ug/L
Chromium	2	4-<10	11	0-28	ug/L
Copper	2	1-3	11	0-110	ug/L
Iron	22	0-150	11	170-2500	ug/L
Lead	2	1-<9	11	<100	ug/L
Lithium	2	80-110	11	10-150	ug/L
Manganese	2	40-50	11	30-140	ug/L
Mercury	2	.0-<.1	11	.0-.2	ug/L
Molybdenum	2	<3-4	11	0-4	ug/L
Nickel	2	2-<6	11	0-<50	ug/L
Selenium	1	4	11	0-3	ug/L
Vanadium	2	1.1-<4.0	---	---	ug/L
Zinc	2	4-10	6	0-70	ug/L

Figure 33.--Continued.

Bear Creek at Otter

Bear Creek is a tributary stream to Otter Creek and was sampled 2.6 miles upstream from the mouth at station 21. The channel near the sampling site is deeply entrenched and covered with grass and shrubs. The drainage area upstream from the station is 90.4 mi^2.

Streamflow was present at times of snowmelt and storms. When the surface supply was adequate to recharge shallow ground-water aquifers, flows continued after the main runoff. Four samples were collected during the 1975 water year and one during the 1976 water year. Discharges at the time of sample collection ranged from 0.01 to 53 ft^3/s. The three higher flows (above 7 ft^3/s) resulted from rapid runoff and high stream velocities. The samples from lower flows were collected as water moved slowly between pools.

A sample collected on May 22, 1975, had the highest dissolved-solids concentration at 2,330 mg/L, although it was not from the lowest flow. The water was a sodium sulfate type (fig. 34) that evidently had been affected by subsurface solution. Water from the highest sampled flow on March 5, 1975, had a dissolved-solids concentration of 140 mg/L. The cation and anion ratios had increased percentages of calcium and bicarbonate, respectively.

Suspended sediment was relatively low in all samples. Upstream impoundments were responsible as was the partly frozen ground during periods when three of the five samples were collected. Because of low amounts of sediment, only moderate values were detected for those constituents analyzed from the water-sediment mixture (fig. 34).

Threemile Creek near Ashland

Threemile Creek is a small tributary to Otter Creek having a drainage area of 51.5 mi^2. It was sampled 1.5 miles upstream from the mouth (station 22) and flowed on only two visits during the study period. Both flows were of short duration and the result of snowmelt and rainfall. Samples collected on January 20 and March 19, 1975, respectively, had discharges of 1.8 and 22 ft^3/s.

Runoff conditions differed with the two flows and accounted for some variation in dissolved solids. The January sample, from runoff over partly frozen ground, had a dissolved-solids concentration of 149 mg/L. Dissolved-solids concentration for the March sample was about 20 percent higher and the calculated load was 10.8 tons/day. For both samples the cation ratio had nearly equal percentages of sodium, calcium, and magnesium (fig. 35). Among the anions bicarbonate slightly exceeded sulfate.

BOD and total phosphorus concentrations were high owing to the flushing of organic particles. Low flow and frozen ground at the time of the January sample caused a low suspended-sediment concentration of 24 mg/L. The March sample had a suspended-sediment concentration of 212 mg/L and a calculated load of 13 tons/day (fig. 35).

Beaver Creek near Ashland

Beaver Creek, sampled 0.8 mile upstream from the mouth at station 23, has a drainage area of 92.3 mi^2. The margins of the gravel channel near the station are covered with grass, brush, and trees. Some pooling was evident in the downstream parts of the drainage during low flow. The streams had flow during five of the station visits in the 1975 water year and on four of the visits in 1976.

Samples from runoff on January 20 and March 1, 1975, with respective discharges of 42 and 36 ft^3/s, were collected under ice conditions when the ground was partly frozen. On March 19, 1975, after increased thawing, a third runoff sample was collected from a flow of 29 ft^3/s. The remaining six samples were taken from flows of 3 ft^3/s or less. The low-flow water was from a combination of rain and discharge from alluvial aquifers.

The water contained principally sodium, magnesium, and sulfate for all samples (fig. 36). However, the higher flows had greater percentages of calcium and bicarbonate in their respective cation and anion ratios. Dissolved-solids concentrations for the six low-flow samples were consistently near 3,000 mg/L. The minimum dissolved-solids concentration was from the January 20, 1975, sample.

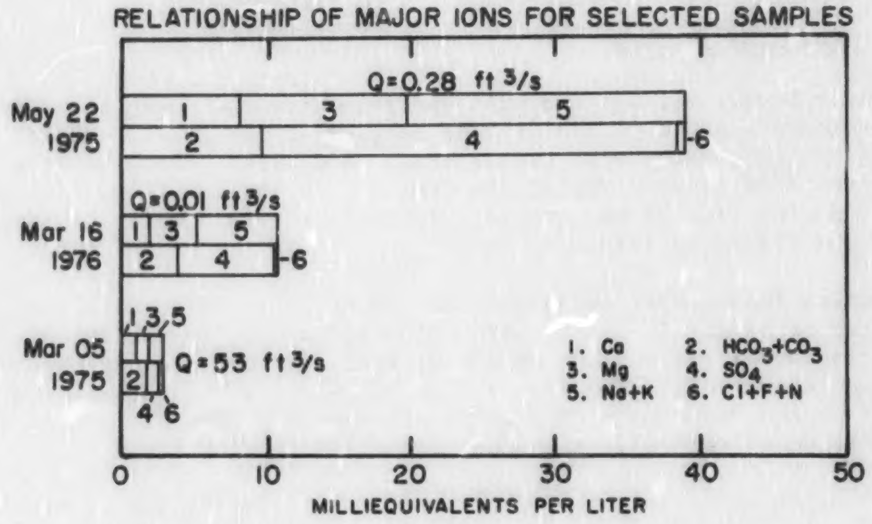
Like other small streams, the BOD and total phosphorus concentrations were highest during the high runoff periods--especially at times when the ground was partly frozen. Suspended-sediment concentrations were much lower than found at most other streams. The highest value was a moderate 73 mg/L from the March 19, 1975, sample (fig. 36). The low suspended-sediment concentration accounted for lower values of most constituents analyzed from the water-sediment mixture.

Liscom Creek near Ashland

Liscom Creek, having a drainage area of 47.6 mi^2, was one of the smaller streams sampled. The stream gradient upstream from the site (station 24) is sufficient to cause rapid runoff; however, between the station and the stream mouth ponding was evident much of the year. Subsurface sources furnished water to the ponds during periods of no surface flow.

Owing to the small drainage and rapid runoff, streamflow was infrequent. Samples were collected on January 21, 1975, from a flow of 9.9 ft^3/s and on March 1, 1975, from a flow of 18 ft^3/s. Both samples were collected during ice conditions, at times when the ground was mostly frozen.

Water from both samples was a calcium bicarbonate type having low dissolved-solids concentration (fig. 37). Frozen ground and fast runoff allowed only limited solution to occur, causing the water to reflect characteristics of rainfall and snowmelt. Generally, the chemical constituents had values very close to those found at other stations during high-runoff periods.



SUSPENDED SEDIMENT FOR SELECTED DAYS

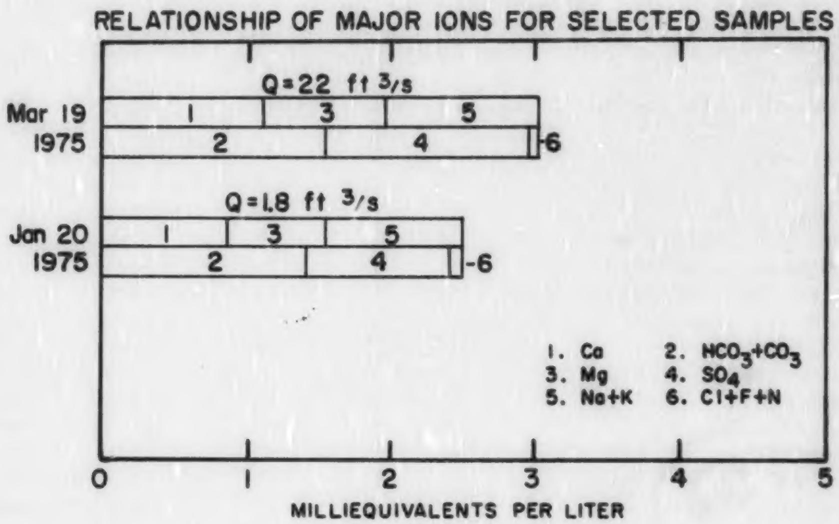
	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1975	Jan. 20	1315	0.0	7.1	79	1.5
	Mar. 05	0930	.0	53	51	7.3
	Mar. 19	1020	2.0	15	92	3.7
	May 22	1440	14.0	.28	56	.04
1976	Mar. 16	1600	.0	.01	27	.00

Figure 34.--Relationships of major ions, suspended sediment, and analytical values for Bear Creek at Otter (station 21).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	5		0.01-53	ft^3/s
Specific conductance (at 25 deg. C)	5	1070	225-3000	umhos/cm
pH	5	7.9	7.0-8.4	units
Temperature	5	3.0	0.0-14	deg. C
Turbidity	5	25	3-50	JTU
Dissolved oxygen	5	79	59-91	percent
Biochemical oxygen demand	4	8.9	2.4-14	mg/L
Calcium (Ca), dissolved	5	56	21-160	mg/L
Magnesium (Mg), dissolved	5	49	9-150	mg/L
Sodium (Na), dissolved	5	120	14-390	mg/L
Percent sodium	5	38	24-49	percent
Sodium-adsorption ratio	5	2.5	.6-5.3	---
Potassium (K), dissolved	5	11	5.8-18	mg/L
Bicarbonate (HCO_3)	5	227	69-584	mg/L
Carbonate (CO_3)	5	0	0	mg/L
Sulfate (SO_4), dissolved	5	400	47-1300	mg/L
Chloride (Cl), dissolved	5	6.1	2.6-13	mg/L
Fluoride (F), dissolved	5	.3	.1-.6	mg/L
Silica (SiO_2), dissolved	5	8.6	6.1-14	mg/L
Dissolved solids (calculated)	5	767	140-2330	mg/L
Nitrite plus nitrate, total as N	5	.08	.1-.16	mg/L
Nitrogen, ammonia, total as N	5	.06	.03-.11	mg/L
Nitrogen, total organic as N	5	1.0	.57-1.4	mg/L
Nitrogen, total kjeldahl as N	5	1.0	.60-1.4	mg/L
Phosphorus, total as P	5	.18	.02-.27	mg/L
Suspended sediment	5	61	27-92	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	---	---	ug/L
Arsenic	---	---	1	2	ug/L
Beryllium	---	---	1	<10	ug/L
Boron	5	70-330	---	---	ug/L
Cadmium	---	---	1	10	ug/L
Chromium	---	---	1	10	ug/L
Copper	---	---	1	90	ug/L
Iron	5	80-160	1	1600	ug/L
Lead	---	---	1	<100	ug/L
Lithium	---	---	1	20	ug/L
Manganese	---	---	1	110	ug/L
Mercury	---	---	1	.0	ug/L
Molybdenum	---	---	1	1	ug/L
Nickel	---	---	1	<50	ug/L
Selenium	---	---	1	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	---	---	ug/L

Figure 34.--Continued



SUSPENDED SEDIMENT FOR SELECTED DAYS

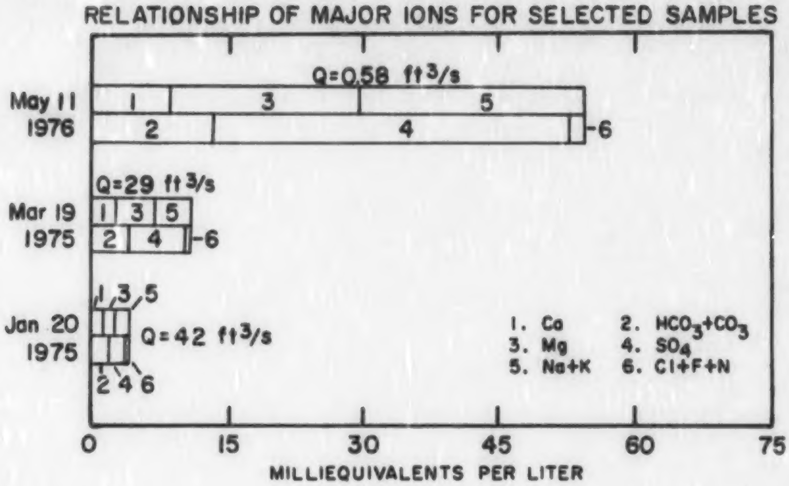
	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1975	Jan. 20	0930	0.0	1.8	24	0.12
	Mar. 19	1245	3.5	22	212	13

Figure 35.--Relationships of major ions, suspended sediment, and analytical values for Threemile Creek near Ashland (station 22).

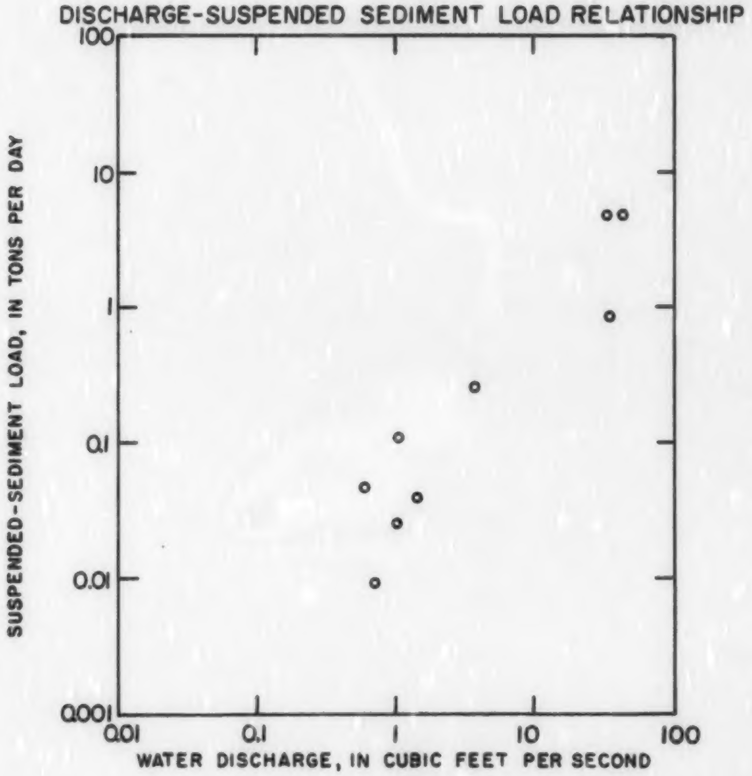
PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	2		1.8-22	ft^3/s
Specific conductance (at 25 deg. C)	2	308	260-355	umhos/cm
pH	2	7.6	7.5-7.6	units
Temperature	2	2.0	0.0-3.5	deg. C
Turbidity	2	60	20-100	JTU
Dissolved oxygen	2	88	86-89	percent
Biochemical oxygen demand	2	10	10	mg/L
Calcium (Ca), dissolved	2	20	17-22	mg/L
Magnesium (Mg), dissolved	2	9.1	8.2-10	mg/L
Sodium (Na), dissolved	2	19	18-20	mg/L
Percent sodium	2	30	29-31	percent
Sodium-adsorption ratio	2	.9	.9	---
Potassium (K), dissolved	2	7.7	7.0-8.4	mg/L
Bicarbonate (HCO_3)	2	88	80-95	mg/L
Carbonate (CO_3)	2	0	0	mg/L
Sulfate (SO_4), dissolved	2	58	49-67	mg/L
Chloride (Cl), dissolved	2	2.0	2.0	mg/L
Fluoride (F), dissolved	2	.3	.1-.4	mg/L
Silica (SiO_2), dissolved	2	5.7	5.1-6.2	mg/L
Dissolved solids (calculated)	2	165	149-181	mg/L
Nitrite plus nitrate, total as N	2	.05	.04-.06	mg/L
Nitrogen, ammonia, total as N	2	.05	.01-.09	mg/L
Nitrogen, total organic as N	2	1.2	1.0-1.3	mg/L
Nitrogen, total kjeldahl as N	2	1.2	1.1-1.3	mg/L
Phosphorus, total as P	2	.26	.16-.36	mg/L
Suspended sediment	2	118	24-212	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	0	---	---	ug/L
Arsenic	1	4	1	3	ug/L
Beryllium	1	0	1	<10	ug/L
Boron	2	110	---	---	ug/L
Cadmium	1	0	1	20	ug/L
Chromium	1	0	1	10	ug/L
Copper	1	8	1	50	ug/L
Iron	2	60-190	1	1500	ug/L
Lead	1	6	1	<100	ug/L
Lithium	---	---	1	10	ug/L
Manganese	1	20	1	60	ug/L
Mercury	1	0	1	.0	ug/L
Molybdenum	---	---	1	0	ug/L
Nickel	1	2	1	<50	ug/L
Selenium	---	---	1	3	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	1	20	---	---	ug/L

Figure 35.--Continued.



RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



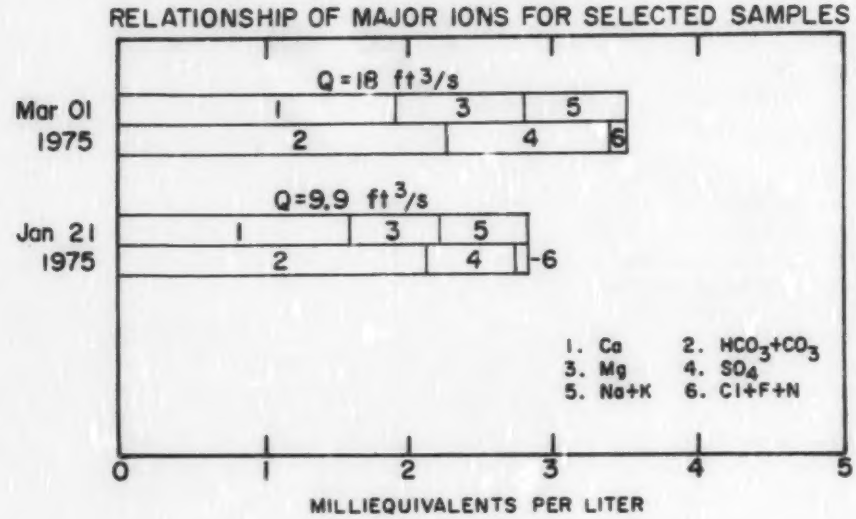
DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 36.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Beaver Creek near Ashland (station 23).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	9		0.58-42	ft^3/s
Specific conductance (at 25 deg. C)	9	2780	400-4080	umhos/cm
pH	9	8.0	7.7-8.3	units
Temperature	9	7.5	0.0-15.5	deg. C
Turbidity	9	10	1-40	JTU
Dissolved oxygen	9	81	63-103	percent
Biochemical oxygen demand	8	4.3	1.1-11	mg/L
Calcium (Ca), dissolved	9	110	20-170	mg/L
Magnesium (Mg), dissolved	9	160	15-260	mg/L
Sodium (Na), dissolved	9	340	30-560	mg/L
Percent sodium	9	41	33-47	percent
Sodium-adsorption ratio	9	4.5	1.2-6.4	---
Potassium (K), dissolved	9	18	9.4-25	mg/L
Bicarbonate (HCO_3)	9	521	94-755	mg/L
Carbonate (CO_3)	9	0	0	mg/L
Sulfate (SO_4), dissolved	9	1200	100-2000	mg/L
Chloride (Cl), dissolved	9	7.0	1.2-11	mg/L
Fluoride (F), dissolved	9	.4	.1-.5	mg/L
Silica (SiO_2), dissolved	9	11	5.6-15	mg/L
Dissolved solids (calculated)	9	2150	230-3400	mg/L
Nitrite plus nitrate, total as N	9	.04	.01-.15	mg/L
Nitrogen, ammonia, total as N	9	.06	.00-.34	mg/L
Nitrogen, total organic as N	9	1.1	.22-2.4	mg/L
Nitrogen, total kjeldahl as N	9	1.1	.22-2.4	mg/L
Phosphorus, total as P	9	.08	.01-.19	mg/L
Suspended sediment	9	29	6-73	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	2	70-100	ug/L
Arsenic	---	---	3	2-10	ug/L
Beryllium	---	---	3	0-<10	ug/L
Boron	9	140-940	---	---	ug/L
Cadmium	---	---	3	<10-20	ug/L
Chromium	---	---	3	0-10	ug/L
Copper	---	---	3	10-50	ug/L
Iron	9	10-180	3	280-1600	ug/L
Lead	---	---	3	<100	ug/L
Lithium	---	---	3	20-140	ug/L
Manganese	---	---	3	50-140	ug/L
Mercury	---	---	3	.0	ug/L
Molybdenum	---	---	3	0-3	ug/L
Nickel	---	---	3	<50	ug/L
Selenium	---	---	3	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	2	30-50	ug/L

Figure 36.--Continued.



SUSPENDED SEDIMENT FOR SELECTED DAYS

	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1975	Jan. 21	1420	0.0	9.9	63	1.7
	Mar. 01	1400	.0	18	223	11

Figure 37.--Relationship of major ions, suspended sediment, and analytical values for Liscom Creek near Ashland (station 24).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	2		9.9-18	ft^3/s
Specific conductance (at 25 deg. C)	2	128	120-135	umhos/cm
pH	2	8.0	7.7-8.2	units
Temperature	2	.0	0.0	deg. C
Turbidity	2	50	50	JTU
Dissolved oxygen	2	90	89-91	percent
Biochemical oxygen demand	2	7.6	6.8-8.3	mg/L
Calcium (Ca), dissolved	2	18	17-19	mg/L
Magnesium (Mg), dissolved	2	4.7	3.9-5.5	mg/L
Sodium (Na), dissolved	2	4.2	3.7-4.6	mg/L
Percent sodium	2	12	11-12	percent
Sodium-adsorption ratio	2	.2	.2	---
Potassium (K), dissolved	2	5.7	5.4-5.9	mg/L
Bicarbonate (HCO_3)	2	65	60-69	mg/L
Carbonate (CO_3)	2	0	0	mg/L
Sulfate (SO_4), dissolved	2	21	15-27	mg/L
Chloride (Cl), dissolved	2	1.8	1.6-2.0	mg/L
Fluoride (F), dissolved	2	.1	.0-.1	mg/L
Silica (SiO_2), dissolved	2	6.2	5.4-7.0	mg/L
Dissolved solids (calculated)	2	94	84-103	mg/L
Nitrite plus nitrate, total as N	2	.09	.01-.16	mg/L
Nitrogen, ammonia, total as N	2	.03	.02-.04	mg/L
Nitrogen, total organic as N	2	1.4	1.4	mg/L
Nitrogen, total kjeldahl as N	2	1.4	1.4	mg/L
Phosphorus, total as P	2	.23	.19-.26	mg/L
Suspended sediment	2	143	63-223	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	---	---	ug/L
Arsenic	---	---	1	2	ug/L
Beryllium	---	---	1	<10	ug/L
Boron	2	90-110	---	---	ug/L
Cadmium	---	---	1	10	ug/L
Chromium	---	---	1	0	ug/L
Copper	---	---	1	<10	ug/L
Iron	2	70-140	1	1700	ug/L
Lead	---	---	1	<100	ug/L
Lithium	---	---	1	10	ug/L
Manganese	---	---	1	30	ug/L
Mercury	---	---	1	.0	ug/L
Molybdenum	---	---	1	0	ug/L
Nickel	---	---	1	50	ug/L
Selenium	---	---	1	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	---	---	ug/L

Figure 37.--Continued.

The January sample had a suspended-sediment concentration of 63 mg/L and the March sample was 223 mg/L. The difference may have resulted from the higher March flow and the probability that the surface had thawed more at this later date. The March sample had a calculated suspended-sediment load of 11 tons/day (fig. 37).

Foster Creek near Volborg

Foster Creek, having a drainage area of 116 mi^2, is one of the larger tributary streams discussed in this section The channel in the lower reaches is entrenched several feet, generally stable, and covered with grass and shrubs. Streamflow at this site (station 25) during the study was intermittent throughout the winter and spring and absent in summer and fall. Sources of water were from both direct runoff and alluvial-aquifer discharge. Eleven samples were collected--6 in the 1975 water year and 5 in 1976.

The highest flows sampled were 300 and 51 ft^3/s on March 1 and April 24, 1975, respectively. All other flows were less than 10 ft^3/s; four were under 1 ft^3/s.

With the exception of the highest flow, water was always a sodium sulfate type (fig. 38). Both constituents were in excess of 70 percent in their cation and anion ratios. The high-flow sample, although not definitely a sodium sulfate type water, was influenced by these two ions with each making up about 45 percent of their respective cation and anion ratios. Water type at this station differed from that of upstream tributaries and was similar to the water of Pumpkin Creek. Drainages of both Foster and Pumpkin Creeks are formed in the Tullock and Lebo Shale Members of the Fort Union Formation; all upstream stations in the Tongue River drainage lie in the Tongue River Member of this formation.

Dissolved-solids concentration ranged from 133 to 3,190 mg/L. The lower concentrations were analyzed from samples collected at high flow during frozen-ground conditions. Higher concentrations were generally found at low flows having a ground-water source. Other chemical constituents had patterns and ranges that paralleled those of upstream stations.

Suspended-sediment concentrations at this station had a wider range and were generally higher than at other tributary streams. The high concentration of 4,260 mg/L occurred on June 15, 1976, after a 4- to 5-day period of rain. Although streamflow was relatively low at 4.4 ft^3/s, the overland runoff after a long dry period carried many sediment fines into the stream. The maximum calculated suspended-sediment load of 105 tons/day (fig. 38) occurred during the highest flow from a sediment concentration of 130 mg/L.

Areal correlation

The Tongue River Dam, surface and ground-water inflow, and irrigation practices all combine to affect the streamflow within the reach of the river studied. Streamflow is highly regulated by the dam with the peak flows generally reduced. In comparing mean annual discharges for stations at the dam and at the mouth during the past 30 years, a downstream loss of almost 5 percent is evident, although the 1975 water year did have a gain. Evidence indicates that tributaries and ground water do contribute to the Tongue River streamflow; however, evaporation and transpiration from irrigation practices and natural processes generally result in an overall depletion.

The major ions in milliequivalents as analyzed from samples collected at the four river stations during October 1975 are shown in figure 39. Although a lag of almost 2 weeks existed between sample collection at the two upstream and two downstream stations, streamflow was constant and the water quality presumably changed little.

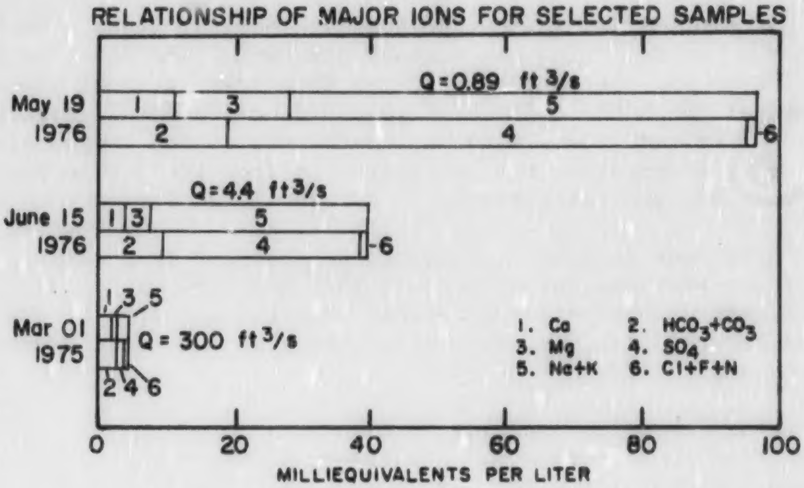
Figure 39A shows an increase in dissolved-solids concentration of about 35 percent from the Tongue River Dam to the confluence with the Yellowstone River. The increase is uniform between stations and due to surface and subsurface inflow. In comparing the mean dissolved-solids concentration for the entire water year, however, only a 20-percent increase is apparent, and at times of high surface runoff there was an actual downstream decrease in concentration.

The graph shows only slight variations in major ions between the three upstream stations and significant changes from the Brandenberg Bridge stations to the mouth. Both sodium and sulfate have large increases in the lower drainage while the other ions remain nearly constant. River contributions downstream from Brandenberg Bridge are apparently of a water containing high concentrations of both sodium and sulfate.

The changes in water type correlate well with geologic formations. The three upstream stations (stations 10, 12, 14) are fed by drainages underlain almost entirely by the Tongue River Member of the Fort Union Formation. This accounts for the consistency in the chemical character of the water between the three. From near Brandenberg to the mouth, the river transects the Lebo and Tullock Members. The relative downstream increases in proportions of sodium and sulfate reflect the change in lithology. Two downstream tributaries, Foster Creek and Pumpkin Creek, also drain the two lower members of the Fort Union Formation and contain water dominated by sodium and sulfate ions.

Figure 39A depicts water that is found at near-base-flow conditions. Most of the modifications in water type throughout the rest of the year can be attributed to dilution from surface runoff, both upstream and downstream from the Tongue River Dam. The runoff water is of a calcium bicarbonate type having a low concentration of dissolved solids. Apparently the sodium and sulfate ions that are absent from the runoff water have been leached from surface soils and are more available to subsurface water. The presence of bicarbonate at or near the surface may result from biochemical activity within the soil on carbon dioxide provided by the atmosphere.

The suspended-sediment graph (fig. 39B) shows small to moderate concentration increases in the upper stream sections and more pronounced increases



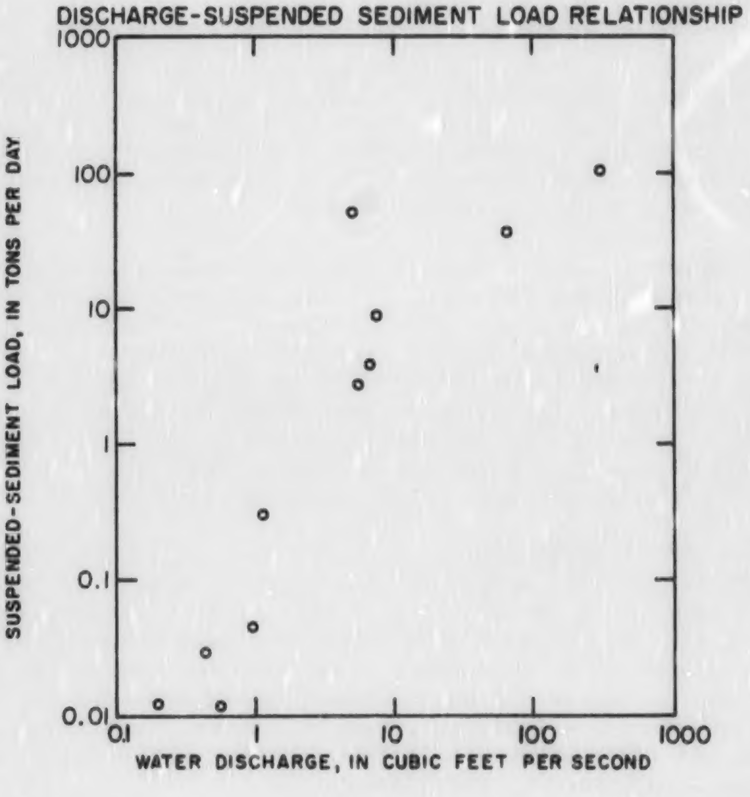


Figure 38.--Relationship of major ions, discharge, suspended-sediment load, and analytical values for Foster Creek near Volborg (station 25).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	11		0.13-300	ft^3/s
Specific conductance (at 25 deg. C)	11	2370	170-4300	umhos/cm
pH	11	7.9	7.2-8.3	units
Temperature	11	8.0	0.0-22.5	deg. C
Turbidity	11	250	8-2200	JTU
Dissolved oxygen	11	84	63-94	percent
Biochemical oxygen demand	11	4.5	2.0-8.1	mg/L
Calcium (Ca), dissolved	11	60	15-110	mg/L
Magnesium (Mg), dissolved	11	54	5.9-110	mg/L
Sodium (Na), dissolved	11	420	20-780	mg/L
Percent sodium	11	68	39-80	percent
Sodium-adsorption ratio	11	9.0	1.1-13	---
Potassium (K), dissolved	11	8.3	5.0-12	mg/L
Bicarbonate (HCO_3)	11	335	69-578	mg/L
Carbonate (CO_3)	11	1	0-11	mg/L
Sulfate (SO_4), dissolved	11	990	45-1900	mg/L
Chloride (Cl), dissolved	11	9.4	2.6-16	mg/L
Fluoride (F), dissolved	11	.3	.1-.5	mg/L
Silica (SiO_2), dissolved	11	6.9	4.1-9.7	mg/L
Dissolved solids (calculated)	11	1710	133-3190	mg/L
Nitrite plus nitrate, total as N	11	.05	.00-.32	mg/L
Nitrogen, ammonia, total as N	11	.07	.00-.25	mg/L
Nitrogen, total organic as N	11	1.0	.30-1.8	mg/L
Nitrogen, total kjeldahl as N	11	1.1	.48-1.8	mg/L
Phosphorus, total as P	11	.22	.04-.90	mg/L
Suspended sediment	11	507	4-4260	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	3	1900-11000	ug/L
Arsenic	---	---	5	1-4	ug/L
Beryllium	---	---	5	0-<10	ug/L
Boron	11	0-570	---	---	ug/L
Cadmium	---	---	5	<10-10	ug/L
Chromium	---	---	5	0-20	ug/L
Copper	---	---	5	<10-20	ug/L
Iron	11	30-230	5	680-10000	ug/L
Lead	---	---	5	<100	ug/L
Lithium	---	---	5	10-30	ug/L
Manganese	---	---	4	60-170	ug/L
Mercury	---	---	5	0-2	ug/L
Molybdenum	---	---	5	0-1	ug/L
Nickel	---	---	5	<50	ug/L
Selenium	---	---	5	0-1	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	3	50-70	ug/L

Figure 38.--Continued.

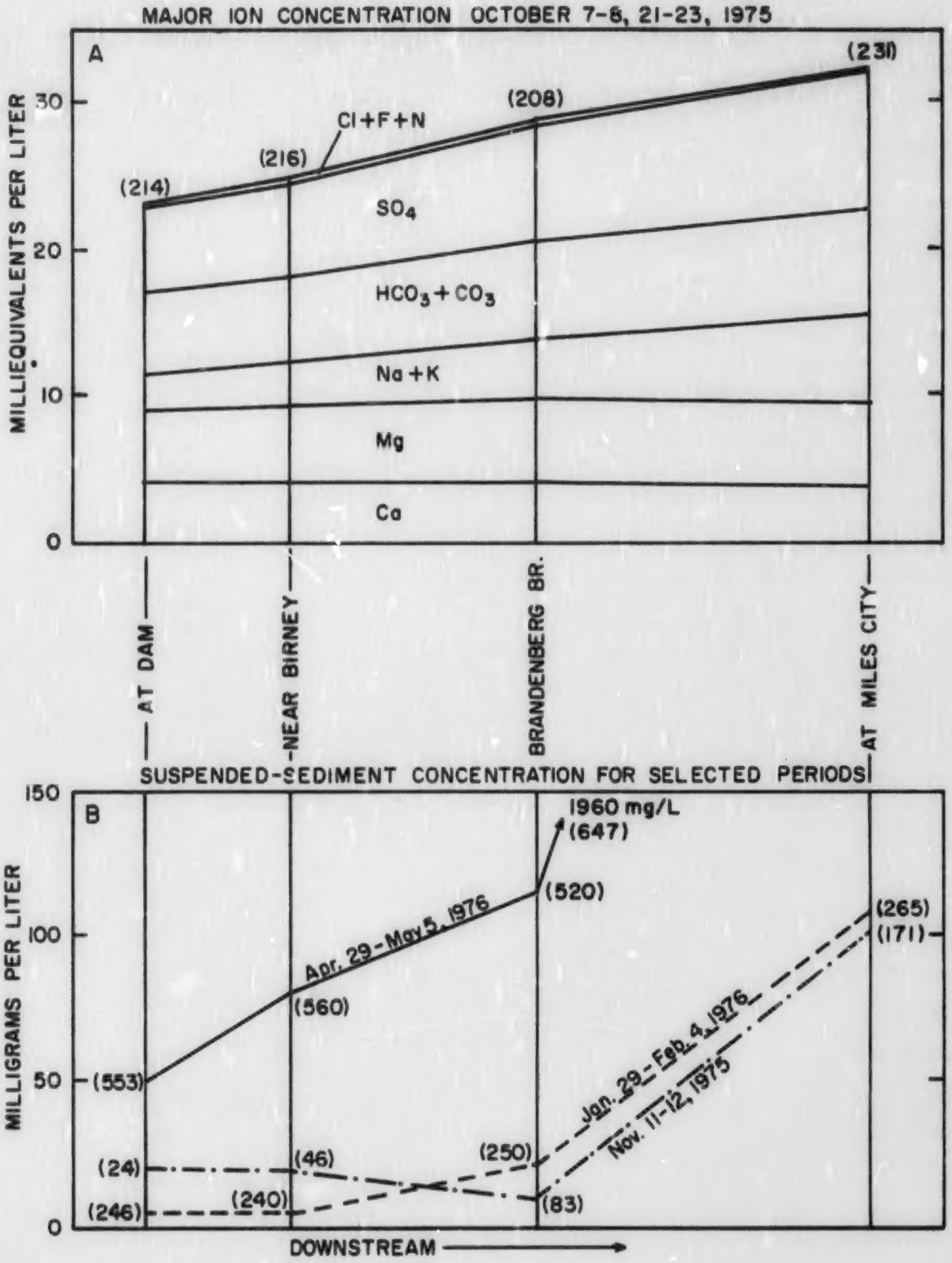


Figure 39.--Concentrations of (A) dissolved constituents and (B) suspended sediment for selected periods on the Tongue River. Numbers in parentheses represent stream discharge at time of sampling, in cubic feet per second.

downstream. Water released from the Tongue River Dam is practically sediment-free. It has a high carrying capacity and generally keeps the upstream channel flushed, as evidenced by the gravel bottom at the upstream stations. Below-average flows, consequently, carry relatively little suspended sediment until channel sources make it more plentiful downstream.

During periods of average through high release from the dam, bank erosion becomes more prevalent. This sediment source along with bottom scouring from increased stream velocities is responsible for higher sediment concentrations. The maximum suspended sediment was measured when high streamflow resulted from surface runoff downstream from the Tongue River Dam. Sediment from the channel and bank erosion was augmented by sediment from overland runoff.

Pumpkin Creek basin

Pumpkin Creek originates about 25 miles north of the Montana-Wyoming border and flows in a northerly direction, entering the Tongue River about 15 miles upstream from its mouth (fig. 1). Although not reflected by streamflow contribution, the 700 mi^2 drainage area of Pumpkin Creek is the largest of all Tongue River tributaries.

Near the mid-drainage of Pumpkin Creek, Little Pumpkin Creek enters the stream from the southwest. Upstream from the intersection of the two streams their respective slopes are 11 and 22 ft/mi, with both transecting the Tongue River Member of the Fort Union Formation. Downstream from the confluence of the streams the slope of Pumpkin Creek decreases to about 6 ft/mi and the channel alluvium overlies the Lebo Shale and Tullock Members of the Fort Union Formation. Throughout most of the drainage the main valley and tributary valleys are topographically mature.

The drainage is used mostly for rangeland with hayfields in the bottomland. There is some flood irrigation and dryland farming. Pumpkin Creek is often ponded in a channel that is frequently dammed for stock watering or irrigation. Streamflow is intermittent throughout much of the drainage with late summer and fall being periods of no flow. Streamflow returns when evaporation and transpiration have decreased and ground-water levels have recovered. The impoundments in the main channel and the many small tributary dams used to capture runoff water have unmeasurable affects on the natural water quality and quantity of Pumpkin Creek.

Four sampling stations on Pumpkin Creek and one station on Little Pumpkin Creek were established in October 1975 (fig. 1). The most upstream station, Pumpkin Creek near Sonnette, was not sampled during the study period because of an absence of flow at the time of station visits. The station near the mouth, Pumpkin Creek near Miles City, has been operated as a continuous-recording streamflow station since October 1972.

Pumpkin Creek near Sonnette

Streamflow at this site (station 26) occurs infrequently. At no station visit was flow present, although ponding throughout the spring and summer was common. The source of the ponded water is ground-water seepage into the low areas. Large flows presumably could result from both snowmelt and storms in the upstream drainage.

Pumpkin Creek near Loesch

Pumpkin Creek near Loesch (station 27) is located 9 miles upstream from Little Pumpkin Creek. Although the drainage area is 102 mi^2, the water sampled was probably representative of only local inflows. The flows sampled were all less than 0.5 ft^3/s and the quality is probably characteristic of water from alluvium. A stock dam about 200 feet upstream from the sampling site controls all but the largest flows. As a result of prevailing low flows, grasses cover the bottom of the channel. During late summer and fall this site is generally dry.

Sodium and sulfate were the dominant ions found in all samples (fig. 40). Sodium consistently ranged between 45 to 51 percent of the cations and sulfate was always greater than 77 percent of the anions. Calcium, magnesium, and bicarbonate were all present in lesser amounts.

With an average of 4,140 mg/L, the dissolved-solids concentration was high when compared with that of other stations in the study area. The range, as noted in figure 40 was somewhat restricted and due to an absence of high surface runoff throughout the sampling period. The highest concentrations were found in late summer and during the winter.

The percent-oxygen saturation was low, averaging 58 percent for the eight samples taken from December through July. The lack of oxygen may be attributed to the inflow of oxygen-depleted ground water, ice cover in the winter, and decomposition of oxidizable material in the summer. BOD concentration reached a maximum of 4.6 mg/L in the July sample. Nutrient concentrations were not unusual for a prairie area; total kjeldahl nitrogen averaged 1.1 mg/L and total phosphorus averaged 0.1 mg/L. Values of pH ranged from 7.5 to 8.1. A sulfur odor was noticed during winter and spring sampling. This was probably from mercaptan associated with decomposing vegetation in an anaerobic environment (Van Voast and Bremmer, 1976).

Concentrations of both dissolved and total trace elements were somewhat variable. A sample taken July 14, 1976, which contained a high boron concentration, also had the highest total manganese concentration for the drainage, 4,500 mg/L, and the second highest sediment concentration, 167 mg/L. The sample also had one of the highest total lithium concentrations (210 mg/L) recorded in the study area.

The water from Pumpkin Creek near Loesch is used for stock watering but has limited value for irrigation because of the generally high dissolved-solids concentration and low flow. During periods of high flow the water may be more suitable for irrigation. The average boron concentration, 1,260 μg/L, was the highest in the Tongue River area but is well below harmful limits for irrigation.

Sediment discharge was erratic at low flows as shown in figure 40. Sediment concentration is influenced by recent rains, cattle activity, and ice cover. The bottom is soft mud that can easily be disturbed. The sediment concentration was low because of extensive ponding and absence of significant flow. High flows, however, would undoubtedly carry a large sediment load from the abundant fine material in the immediate area and from the creek bottom where disturbed by cattle.

Little Pumpkin Creek near Volborg

This is the largest tributary to Pumpkin Creek, draining about 100 mi^2, and nearly equal to the area above Pumpkin Creek near Loesch. Dryland farming is practiced in the sampling area, with irrigation possible only during infrequent periods of surface runoff. Cattle frequent the creek and sampling site. Flow at the site (station 28) generally occurs only during spring runoff or heavy local rains. Ground water apparently does not sustain flow here as it does on Pumpkin Creek. The maximum flow sampled was 0.42 ft^3/s on February 12, 1976. Little Pumpkin Creek is in a deep U-shaped channel that is capable of carrying a large discharge. The Little Pumpkin Creek valley is about the same width as that of Pumpkin Creek above the confluence of the two creeks. The channel is grass covered with some small trees growing in scattered areas. Only three samples were collected--all below a culvert at the downstream end of a pond.

The chemical character of the water was balanced about equally by the cations, sodium and magnesium, with sulfate dominating the anions. Figure 41 shows little difference between any of the samples. The June 9, 1976, sample may have been collected after more evaporation and less surface-runoff contribution, causing a slightly higher dissolved-solids concentration. Dissolved iron and boron were the only trace elements analyzed and both were low.

Aquatic plant growth in the pond was probably responsible for an oxygen saturation of 129 percent in the June 9 sample. This sample also had the highest BOD concentration, 3.2 mg/L, and highest nutrient concentrations of the three samples. Organic nitrogen concentration ranged from 0.76 to 1.2 mg/L for the three samples taken.

The sediment concentration was small owing to ponding, channel vegetation, and low flow. The area is well vegetated and appears to be stabilized against erosion. Therefore, increased flows on Little Pumpkin Creek may not carry as high a sediment load as would be expected on Pumpkin Creek.

Pumpkin Creek near Volborg

This site (station 29) is about 8 miles downstream from the confluence of Little Pumpkin Creek. More than half (386 mi^2) the Pumpkin Creek drainage lies

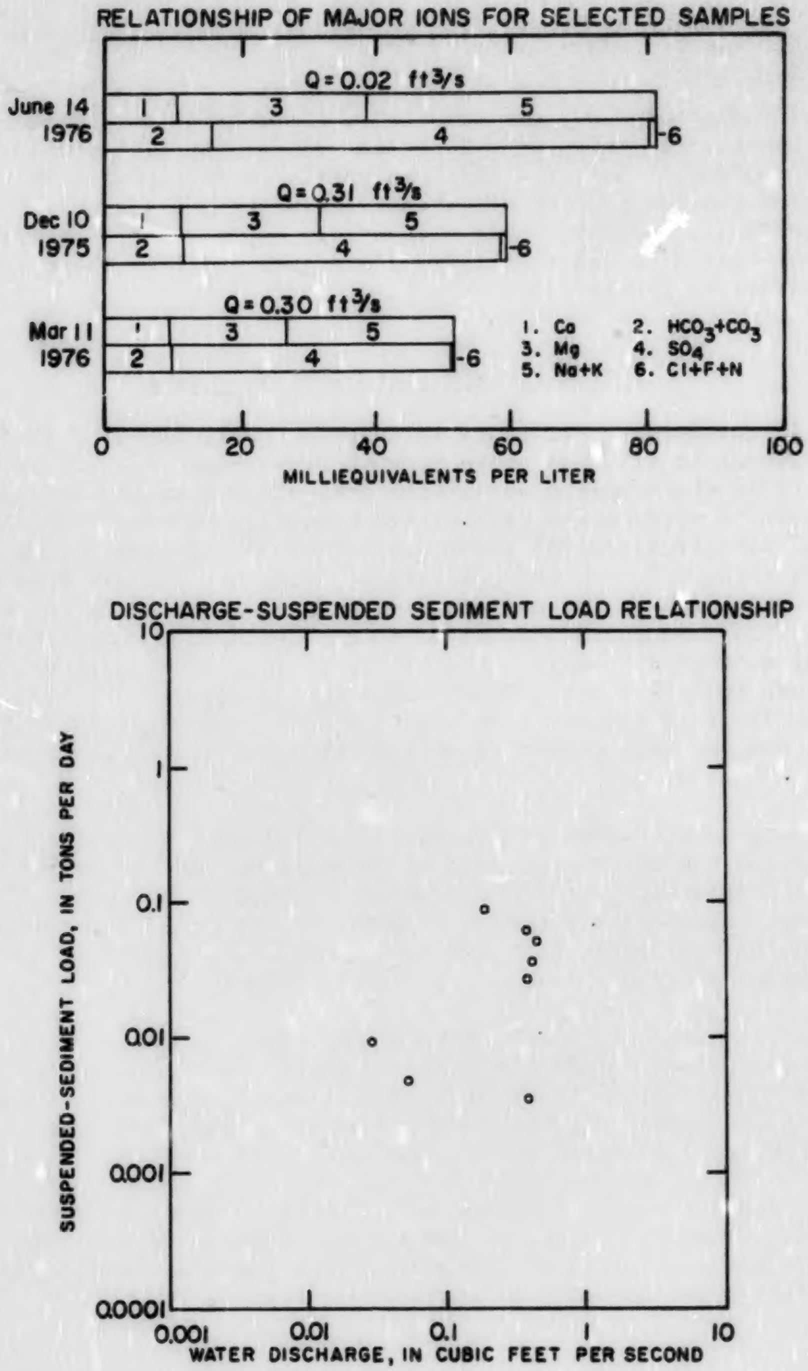
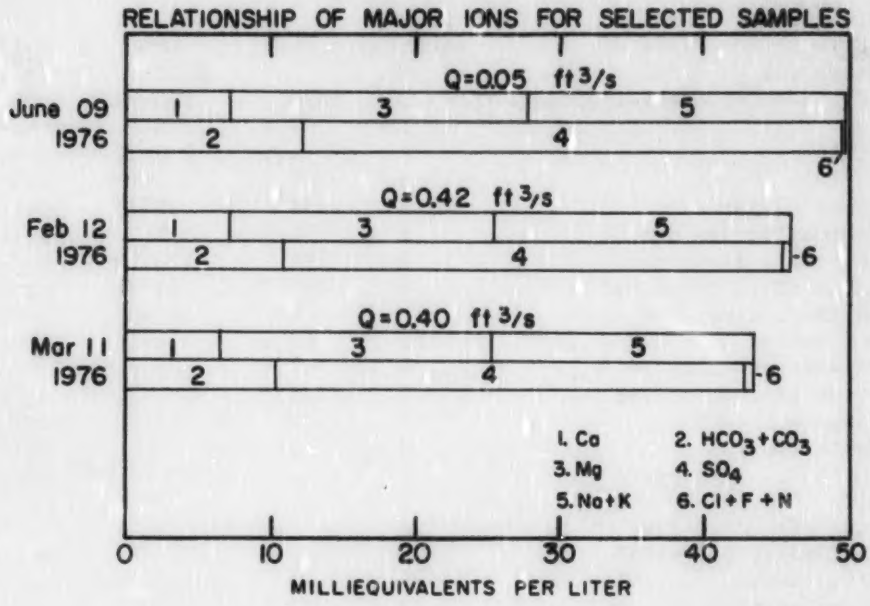


Figure 40.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Pumpkin Creek near Loesch (station 27).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	8		0.02-0.42	ft^3/s
Specific conductance (at 25 deg. C)	8	5020	4100-5900	umhos/cm
pH	8	7.9	7.5-8.1	units
Temperature	8	9.5	0.0-26.0	deg. C
Turbidity	8	6	4-10	JTU
Dissolved oxygen	8	58	29-85	percent
Biochemical oxygen demand	8	1.7	.4-4.6	mg/L
Calcium (Ca), dissolved	8	210	170-260	mg/L
Magnesium (Mg), dissolved	8	270	210-340	mg/L
Sodium (Na), dissolved	8	720	550-960	mg/L
Percent sodium	8	48	46-51	percent
Sodium-adsorption ratio	8	7.7	6.5-9.5	---
Potassium (K), dissolved	8	22	17-26	mg/L
Bicarbonate (HCO_3)	8	719	613-959	mg/L
Carbonate (CO_3)	8	0	0	mg/L
Sulfate (SO_4), dissolved	8	2540	2000-3100	mg/L
Chloride (Cl), dissolved	8	13	1.4-18	mg/L
Fluoride (F), dissolved	8	.5	.4-.6	mg/L
Silica (SiO_2), dissolved	8	15	7.8-24	mg/L
Dissolved solids (calculated)	8	4140	3290-5160	mg/L
Nitrite plus nitrate, total as N	8	.04	.00-.13	mg/L
Nitrogen, ammonia, total as N	8	.03	.00-.13	mg/L
Nitrogen, total organic as N	8	1.1	.62-1.5	mg/L
Nitrogen, total kjeldahl as N	8	1.1	.66-1.5	mg/L
Phosphorus, total as P	8	.10	.01-.45	mg/L
Suspended sediment	8	78	4-225	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	3	60-340	ug/L
Arsenic	---	---	3	0-18	ug/L
Beryllium	---	---	3	0-10	ug/L
Boron	8	1000-1800	---	---	ug/L
Cadmium	---	---	3	<10-10	ug/L
Chromium	---	---	3	0-10	ug/L
Copper	---	---	3	10-20	ug/L
Iron	8	30-160	3	520-1200	ug/L
Lead	---	---	3	<100-100	ug/L
Lithium	---	---	3	140-210	ug/L
Manganese	---	---	3	180-4500	ug/L
Mercury	---	---	3	.0	ug/L
Molybdenum	---	---	3	2-4	ug/L
Nickel	---	---	3	50-100	ug/L
Selenium	---	---	3	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	3	0-30	ug/L

Figure 40.--Continued.



SUSPENDED SEDIMENT FOR SELECTED DAYS

	Date	Time	Temperature (°C)	Instanteneous discharge (ft³/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1976	Feb. 12	1330	1.0	0.42	4	0.00
	Mar. 11	0900	.5	.40	14	.02
	June 09	1150	26.0	.05	56	.01

Figure 41.--Relationships of major ions, suspended sediment, and analytical values for Little Pumpkin Creek near Volborg (station 28).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	3		0.05-0.42	ft^3/s
Specific conductance (at 25 deg. C)	3	3590	3410-3720	umhos/cm
pH	3	8.0	7.8-8.1	units
Temperature	3	9.0	.5-26.0	deg. C
Turbidity	3	3	1-4	JTU
Dissolved oxygen	3	78	40-129	percent
Biochemical oxygen demand	3	1.9	1.1-3.2	mg/L
Calcium (Ca), dissolved	3	130	130-140	mg/L
Magnesium (Mg), dissolved	3	230	220-250	mg/L
Sodium (Na), dissolved	3	450	400-500	mg/L
Percent sodium	3	43	41-44	percent
Sodium-adsorption ratio	3	5.4	5.0-5.9	---
Potassium (K), dissolved	3	26	22-30	mg/L
Bicarbonate (HCO_3)	3	668	624-732	mg/L
Carbonate (CO_3)	3	0	0	mg/L
Sulfate (SO_4), dissolved	3	1700	1600-1800	mg/L
Chloride (Cl), dissolved	3	11	10-12	mg/L
Fluoride (F), dissolved	3	.5	.5-.6	mg/L
Silica (SiO_2), dissolved	3	11	9.7-12	mg/L
Dissolved solids (calculated)	3	2890	2700-3090	mg/L
Nitrite plus nitrate, total as N	3	.01	.01-.02	mg/L
Nitrogen, ammonia, total as N	3	.05	.01-.09	mg/L
Nitrogen, total organic as N	3	1.1	.76-1.2	mg/L
Nitrogen, total kjeldahl as N	3	1.1	.80-1.3	mg/L
Phosphorus, total as P	3	.07	.04-.09	mg/L
Suspended sediment	3	25	4-56	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	---	---	ug/L
Arsenic	---	---	---	---	ug/L
Beryllium	---	---	---	---	ug/L
Boron	3	490-900	---	---	ug/L
Cadmium	---	---	---	---	ug/L
Chromium	---	---	---	---	ug/L
Copper	---	---	---	---	ug/L
Iron	3	50-70	---	---	ug/L
Lead	---	---	---	---	ug/L
Lithium	---	---	---	---	ug/L
Manganese	---	---	---	---	ug/L
Mercury	---	---	---	---	ug/L
Molybdenum	---	---	---	---	ug/L
Nickel	---	---	---	---	ug/L
Selenium	---	---	---	---	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	---	---	ug/L

Figure 41.--Continued.

upstream. Although cattle do not have access to the immediate sampling area because of steep banks, the upstream and downstream reaches have significant exposure. At reduced flows, ponding is common and throughout the spring small dams are constructed for diversion of water for irrigation of hay in the bottomlands. Six samples were collected from flows ranging from 0.02 to 4.6 ft^3/s. From June through September flows were absent at the station.

The chemical character of all water sampled was consistently a sodium sulfate type. Maximum concentration of these ions was 1,300 and 3,600 mg/L, respectively, on December 10, 1975. As illustrated in figure 42, increased streamflow caused the percentage of sodium in the cation ratio to decrease slightly; under the same condition, sulfate remained constant among the anions. Consistency in water type was presumably the result of an absence of high flows.

Dissolved solids were generally high and, like water type, had no major fluctuations. The second lowest concentration of 3,280 mg/L occurred March 10, 1976, from the highest sampled flow. This flow represented the spring runoff from the upper drainage for the year, but is not typical of low concentrations that may be present in peak flows that occur from storms or rapid snowmelt.

The nutrient content from samples at this station was typical of other stations in the Tongue River drainage. The average BOD concentration of 1.7 mg/L was low considering the stream is slow-moving, exposed to cattle and irrigation return flows, and often contains decomposed aquatic vegetation. The SAR and dissolved-solids concentration both presented hazards when the water was classified for irrigation uses. Runoff water was not sampled during the study period.

The water from Pumpkin Creek near Volborg is used for stock watering throughout the year. During periods of runoff, water is diverted from both the main channel and tributaries for irrigation of hayfields. At times other than during runoff, the high dissolved-solids concentrations and low discharges restrict the use of water in Pumpkin Creek for irrigation.

The sediment transported by Pumpkin Creek at the Volborg site was small, as seen in figure 42. Ponding reduced the sediment load by decreasing the water velocity.

Pumpkin Creek near Miles City

This site (station 30) is located 7.5 miles upstream from the confluence with the Tongue River. The upstream drainage is 697 mi^2 with about 3,600 acres under irrigation. The channel is mostly composed of fine gravel, although sediment fines accumulate at the bottom of pools. The series of pools in the stream reach have an abundance of aquatic vegetation and animal life.

Although water-quality sampling began in October 1975, a continuous-recording stream gage has been operated since October 1972. Records show that periods of no flow generally exist in late summer and fall and at times during the winter. Streamflow varies significantly from year to year as exemplified by the mean annual flow for water years 1974, 1975, and 1976 with respective mean daily discharges of 4.5, 33.6, and 15.3 ft^3/s. Streamflow is often less than 1 ft^3/s but spring runoff and storms account for high flows. The maximum recorded discharge was 2,890 ft^3/s on May 6, 1975. Sampled flows ranged from 0.05 to 255 ft^3/s.

With the exception of the high-flow sample on February 13, 1976, the chemical character of the water was always of the sodium sulfate type (fig. 43). Both constituents were always in excess of 60 percent of their respective cation and anion groups. The February sample, greatly reduced in dissolved-solids concentration, retained the sodium-cation domination but had bicarbonate slightly surpassing sulfate among the anions.

In contrast to the upstream stations on Pumpkin Creek, dissolved-solids concentrations fluctuated considerably and the average concentration was much reduced. The highest measured concentration of 3,190 mg/L occurred in mid-winter prior to any runoff. Water from the highest sampled flow had a dissolved-solids concentration of 120 mg/L. The high concentration represents ground-water inflow and the low concentrations resulted from runoff of snowmelt that was unable to penetrate the frozen soil.

Dissolved-oxygen concentrations at this site had less fluctuation than upstream and ranged nearer to saturation. Water pH was slightly higher than most other stations in the study area. Plant nutrient concentrations were generally greater at this site than at upstream stations; however, the highest values did not occur with the highest flow. Again this resulted from frozen soil and the inability of water to pick up and transport particles of organic debris near the ground surface. The nutrient concentration correlated better with suspended-sediment concentrations than with discharge. Both nitrogen and phosphorus concentrations were highest on March 10, 1976, from the second-highest flow sampled.

Dissolved trace constituents were analyzed from the November sample and found to have no unusual concentrations. Total trace constituents were analyzed on five separate samplings. Generally the highest values (fig. 43) were from the July 1976 sample, which had the highest sediment concentration of the five samples. Iron and aluminum had respective concentrations of 4,200 and 4,500 µg/L.

Water uses are primarily for stock watering and irrigation. The quality at this site shows a general improvement in dissolved solids over the upstream stations. Throughout the year it would be suitable for stock. Fortunately, the higher flows that are necessary for irrigation generally contain water of lower dissolved solids. However, it is apparent that for parts of the irrigation season the dissolved-solids concentration and SAR ratios are high enough to limit the usefulness of water for irrigation and, in some cases, cause irrigation hazards.

Flow and ground conditions had a major influence in sediment transport at this site. At lower flows, pool-to-pool movement provides settling time

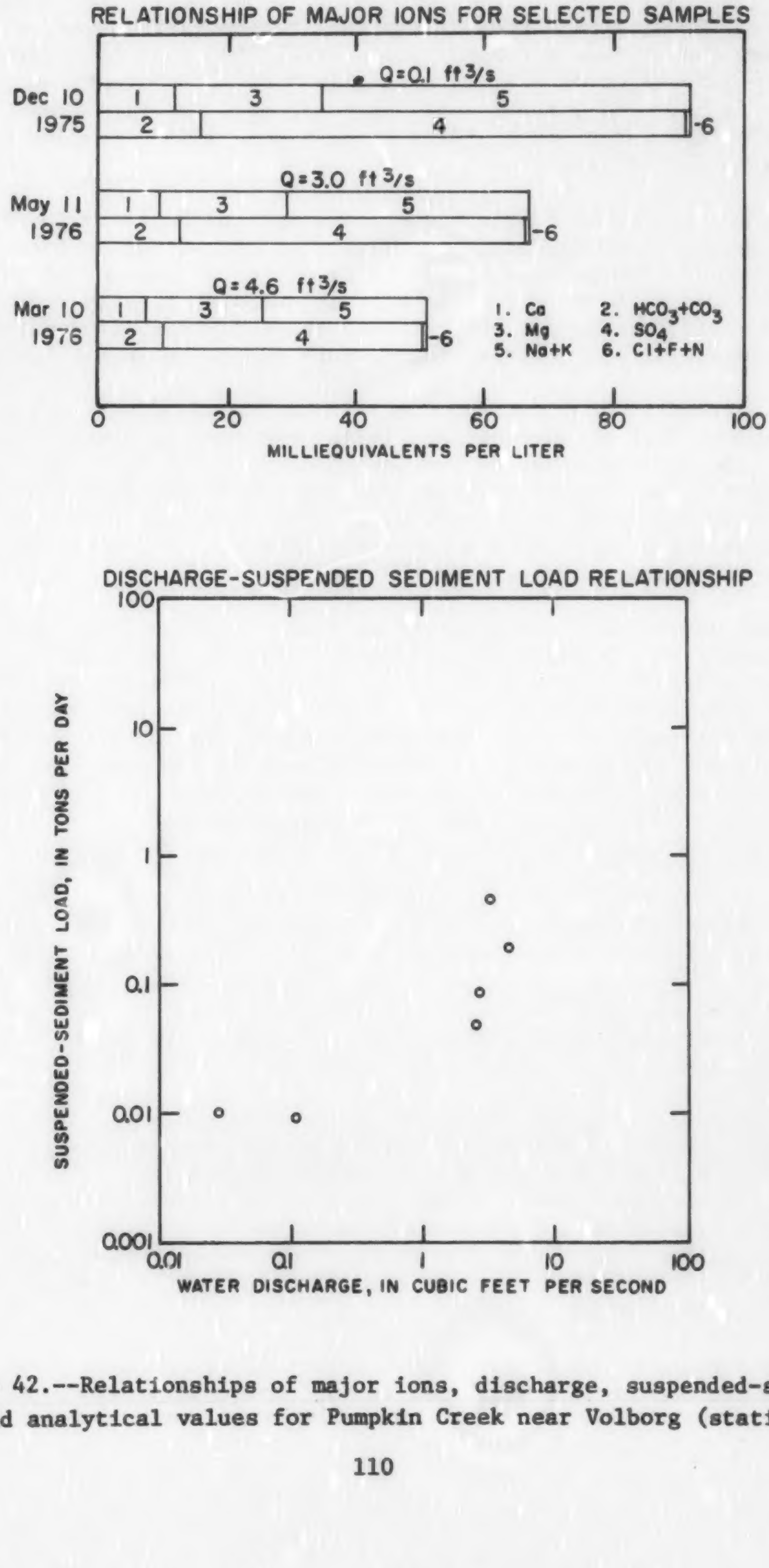
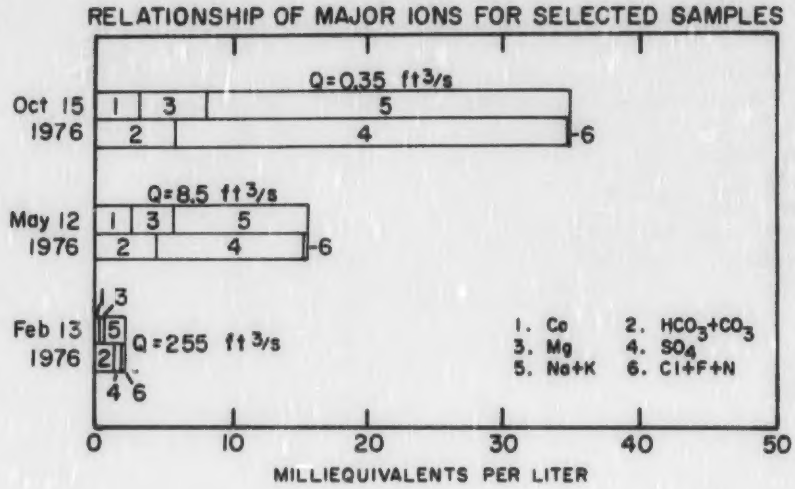


Figure 42.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Pumpkin Creek near Volborg (station 29).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	6		0.02-4.6	ft^3/s
Specific conductance (at 25 deg. C)	6	5090	3880-7000	umhos/cm
pH	6	8.1	8.0-8.4	units
Temperature	6	9.5	0.0-27.0	deg. C
Turbidity	6	5	2-10	JTU
Dissolved oxygen	6	84	63-115	percent
Biochemical oxygen demand	6	1.7	.5-2.6	mg/L
Calcium (Ca), dissolved	6	160	90-230	mg/L
Magnesium (Mg), dissolved	6	220	170-280	mg/L
Sodium (Na), dissolved	6	830	540-1300	mg/L
Percent sodium	6	57	52-62	percent
Sodium-adsorption ratio	6	9.9	7.2-14	---
Potassium (K), dissolved	6	18	15-21	mg/L
Bicarbonate (HCO_3)	6	649	464-961	mg/L
Carbonate (CO_3)	6	0	0	mg/L
Sulfate (SO_4), dissolved	6	2600	1800-3600	mg/L
Chloride (Cl), dissolved	6	18	12-26	mg/L
Fluoride (F), dissolved	6	.4	.3-.6	mg/L
Silica (SiO_2), dissolved	6	6.4	.5-13	mg/L
Dissolved solids (calculated)	6	4120	2980-5950	mg/L
Nitrite plus nitrate, total as N	6	.05	.00-.21	mg/L
Nitrogen, ammonia, total as N	6	.03	.02-.04	mg/L
Nitrogen, total organic as N	6	1.1	.92-1.2	mg/L
Nitrogen, total kjeldahl as N	6	1.1	.96-1.2	mg/L
Phosphorus, total as P	6	.06	.02-.14	mg/L
Suspended sediment	6	55	12-177	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	1	50	ug/L
Arsenic	---	---	1	1	ug/L
Beryllium	---	---	1	0	ug/L
Boron	6	450-960	---	---	ug/L
Cadmium	---	---	1	<10	ug/L
Chromium	---	---	1	10	ug/L
Copper	---	---	1	10	ug/L
Iron	6	10-90	1	380	ug/L
Lead	---	---	1	<100	ug/L
Lithium	---	---	1	100	ug/L
Manganese	---	---	1	150	ug/L
Mercury	---	---	1	.0	ug/L
Molybdenum	---	---	1	4	ug/L
Nickel	---	---	1	50	ug/L
Selenium	---	---	1	0	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	---	---	1	0	ug/L

Figure 42.--Continued.



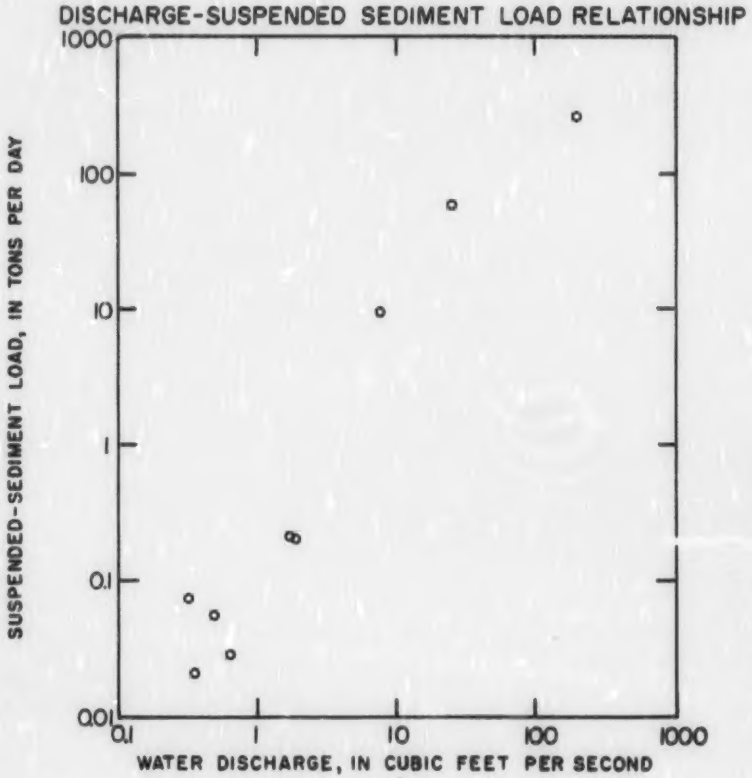


Figure 43.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Pumpkin Creek near Miles City (station 30).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	10		0.05-255	ft^3/s
Specific conductance (at 25 deg. C)	10	2360	195-4120	umhos/cm
pH	10	8.2	7.8-8.6	units
Temperature	10	9.5	0.0-29.5	deg. C
Turbidity	10	101	7-410	JTU
Dissolved oxygen	10	92	65-111	percent
Biochemical oxygen demand	10	3.4	.6-9.8	mg/L
Calcium (Ca), dissolved	10	57	8.7-100	mg/L
Magnesium (Mg), dissolved	10	47	3.5-89	mg/L
Sodium (Na), dissolved	10	420	26-830	mg/L
Percent sodium	10	70	57-78	percent
Sodium-adsorption ratio	10	9.3	1.9-15	---
Potassium (K), dissolved	10	10	4.6-15	mg/L
Bicarbonate (HCO_3)	10	415	67-876	mg/L
Carbonate (CO_3)	10	6	0-28	mg/L
Sulfate (SO_4), dissolved	10	900	38-1700	mg/L
Chloride (Cl), dissolved	10	7.3	1.8-13	mg/L
Fluoride (F), dissolved	10	.4	.2-.6	mg/L
Silica (SiO_2), dissolved	10	5.4	1.1-11	mg/L
Dissolved solids (calculated)	10	1670	120-3190	mg/L
Nitrite plus nitrate, total as N	10	.13	.00-.37	mg/L
Nitrogen, ammonia, total as N	10	.05	.00-.11	mg/L
Nitrogen, total organic as N	10	1.4	.61-2.5	mg/L
Nitrogen, total kjeldahl as N	10	1.4	.65-2.6	mg/L
Phosphorus, total as P	10	.11	.00-.43	mg/L
Suspended sediment	10	243	21-986	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	20	5	230-4500	ug/L
Arsenic	1	1	5	1-11	ug/L
Beryllium	1	10	5	0-10	ug/L
Boron	10	150-500	---	---	ug/L
Cadmium	1	0	5	0-20	ug/L
Chromium	1	2	5	0-10	ug/L
Copper	1	10	5	10-20	ug/L
Iron	10	0-150	5	150-4200	ug/L
Lead	1	0	5	<100-200	ug/L
Lithium	1	30	5	30-60	ug/L
Manganese	1	10	5	40-120	ug/L
Mercury	1	.2	5	.0-.2	ug/L
Molybdenum	1	0	5	1-5	ug/L
Nickel	1	9	5	<50-100	ug/L
Selenium	1	4	5	0-3	ug/L
Vanadium	1	1.7	---	---	ug/L
Zinc	1	20	5	0-40	ug/L

Figure 43.--Continued.

and produces low-sediment concentrations. High spring flows flush the pools and scour the easily erodible banks increasing the sediment load. At times of overland runoff soils are carried to the stream. Sediment concentrations ranged from 21 to 986 mg/L. The highest sediment load which was dependent on both water discharge and concentration was 388 tons/day for the February 13, 1976, sample (fig. 43).

Areal correlation

Figure 44 shows comparisons of major ions and suspended-sediment concentrations for three stations on Pumpkin Creek. The station Pumpkin Creek near Sonnette is excluded because of the absence of data. Flow from Little Pumpkin Creek enters the main stream between stations near Loesch and Volborg.

Although the major-ion graph (fig. 44A) represents data from one sampling period, it is typical of all sampling done. From the graph two conditions are evident: (1) a decrease in dissolved solids (improvement in water quality) from upstream to downstream and (2) a uniform ratio between the major ions from station to station.

The decrease in dissolved-solids concentration in passage downstream is opposite to the change found on most streams in the study area. Evaporation and transpiration from ponding are, in part, responsible for increasing the dissolved-solids concentration in the upper drainage. Water from downstream contributions is of better quality and acts as a dilutant. Soils also may play an important role in upstream water degradation. Residual soils and those alluvial soils that have been transported but a short distance are common in the upstream drainage. These soils are good contributors of ions to water passing through. Alluvial soils that have been through repeated fluvial processes are dominant in the lower drainages. These alluvial soils, as a result of leaching, have lost many of the ions that are commonly present in the residual soil. Water entering the stream in the lower drainage has passed through the alluvial soils rather than residual soil and, consequently, has a diluting effect on the stream.

The relative consistency of major-ion composition at all stations also differs from most other drainages studied. Pumpkin Creek transects the three members of the Fort Union Formation and apparently the stratigraphic units cause no large changes in the major ions. Because there was little opportunity to sample runoff from snowmelt and storms during the sampling period, water from higher flows may show different relationships than indicated under conditions (1) and (2) above.

The suspended-sediment graph (fig. 44B) shows little change in sediment concentrations between the two upstream stations and a significant increase at moderate flows or above from mid-drainage to the mouth. Stock dams, irrigation dams, and natural pools all tend to reduce sediment movement at low flows. The higher flows, with greater velocities, act to flush the pools and, in addition, erode the streambanks. Samples collected on March 10-11, 1976, illustrate the high-flow condition.

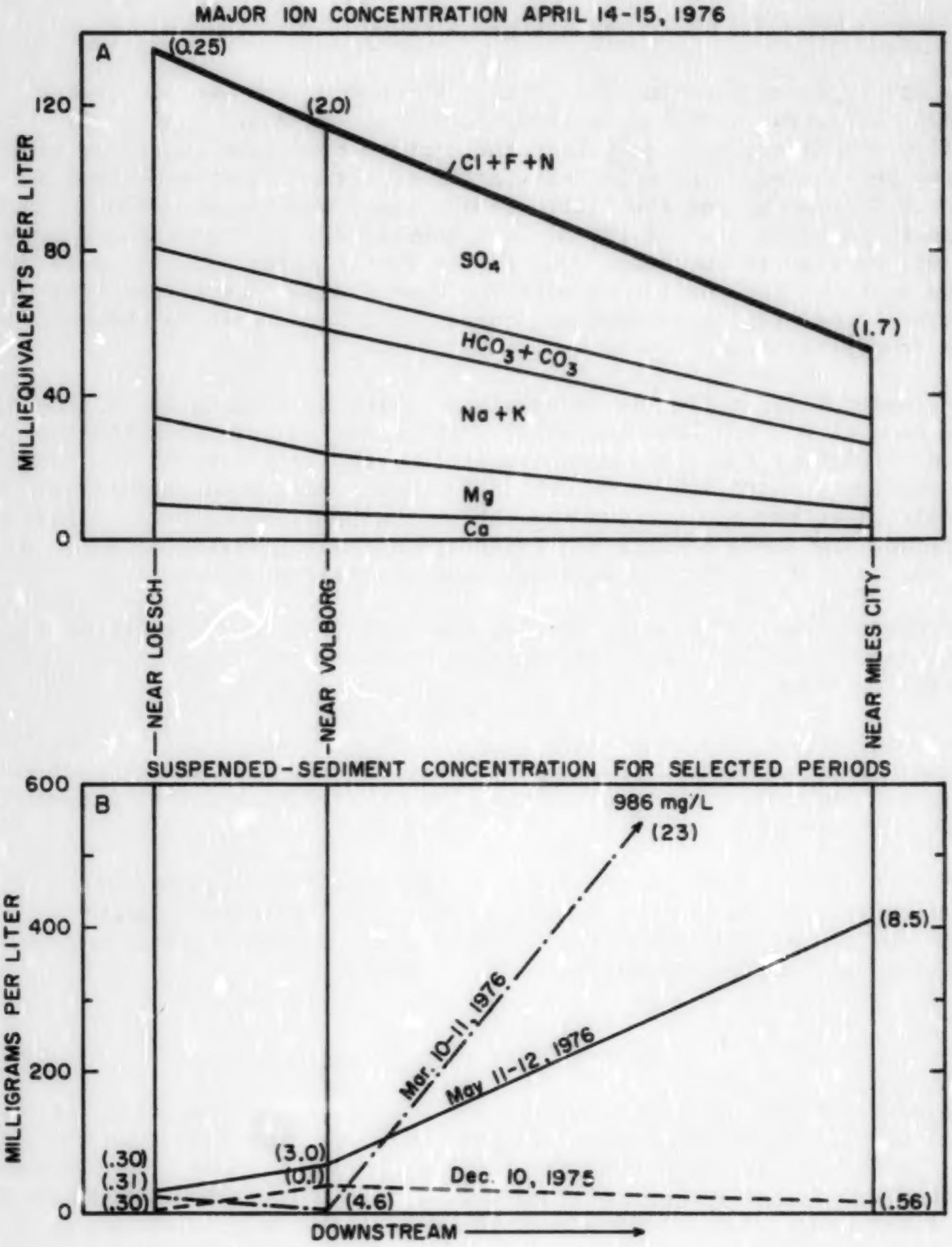


Figure 44.--Concentrations of (A) dissolved constituents and (B) suspended sediment for selected periods on Pumpkin Creek. Numbers in parentheses represent stream discharge at time of sampling, in cubic feet per second.

Powder River basin

The Powder River and its tributaries, which form the second largest drainage in the study area, drain about 13,510 mi^2 in Montana (fig. 1). Most of the flow originates as snowmelt in the Bighorn Mountains southwest of the study area in Wyoming. The main tributaries affecting flow in Montana are Clear Creek in Wyoming and the Little Powder River and Mizpah Creek in Montana. Clear Creek drains an area of the Bighorn Mountains and contributes a large percentage of the flow at Moorhead. The Little Powder River originates in Wyoming and flows north to the confluence with the Powder River downstream from Broadus. Mizpah Creek originates west of Broadus and flows north to the confluence with the Powder River at Mizpah.

The Powder River valley is underlain by alluvium ranging in thickness from 19 to 50 feet (Lewis and Roberts, 1977). The alluvium transects the Fort Union Formation throughout the study area, except for the area between Powderville and the confluence with Ash Creek, which is mostly Hell Creek Formation. Sandstone, siltstone, and shale occur throughout the basin beneath the alluvium. The siltstone and shale beneath the tributary drainage provide an ample source of fine particles that are found in the heavily sediment-laden river.

The Powder River is a wide, meandering, sand-silt bottom river having predominantly low banks and a wide flood plain. The average slope of the river in Montana is 5.5 ft/mi.

The Powder River drainage basin is about 90 percent rangeland that has been heavily used for livestock since the late 1800's. The addition of heavy range use to easily erodible geology increases the erosion rates in the basin. Hayfields are irrigated with water from the river.

Water-quality stations were operated throughout the study period at Moorhead, just north of the Montana-Wyoming border and near Locate, about 27 miles upstream from the mouth. Both stations were also continuous-recording streamflow stations and daily suspended-sediment stations.

Powder River at Moorhead

The Powder River has eroded a deep and relatively narrow valley at Moorhead (station 31) where pine trees inhabit the steep slopes down to the flood plain. The channel is entrenched about 10 to 15 feet and has a mobile sand bottom that varies between a plain and dune bed depending upon the discharge. About 5 miles downstream from Moorhead the valley begins to widen until it is more than a mile wide.

The hydrograph (fig. 45) shows spring runoff starting in March and extending through mid-July. When lower altitudes receive ample moisture, a peak in March or April may occur from early prairie snowmelts. Peaks in late winter and early spring also are caused from ice breakups associated with above-freezing temperatures. Runoff from melting snow at higher altitudes in the Bighorn Mountains begins in mid-May. Runoff in the northern part of the mountains begins in mid-June, increasing flow in Clear Creek. During the summer streamflow decreases, owing to depletion of the snow and water loss through evaporation and transpiration. Further decreases in early winter are caused by ice formation.

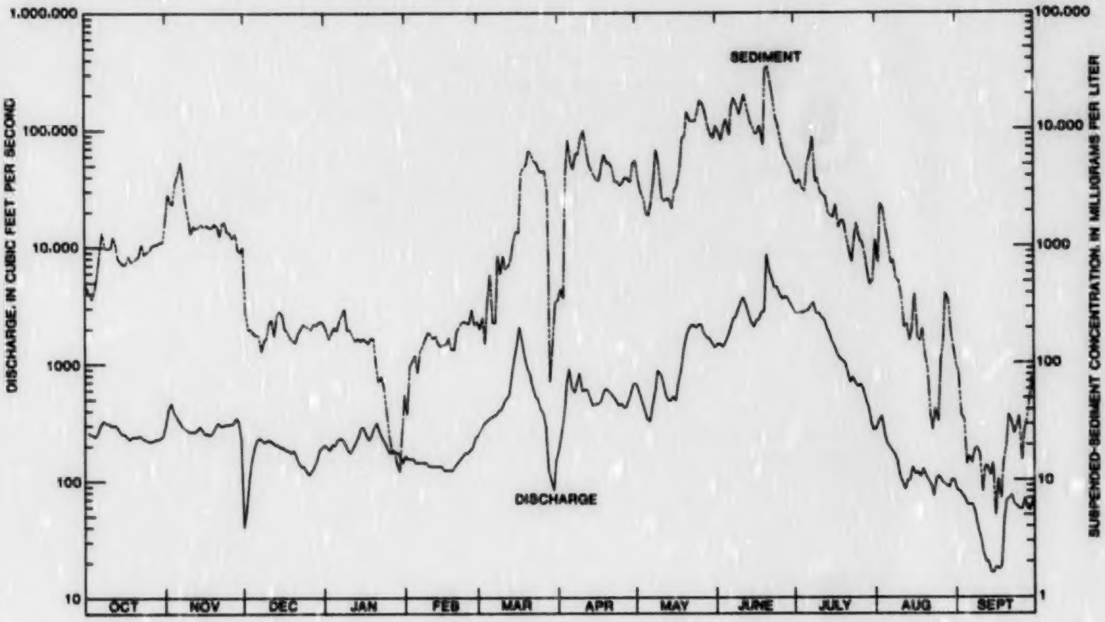
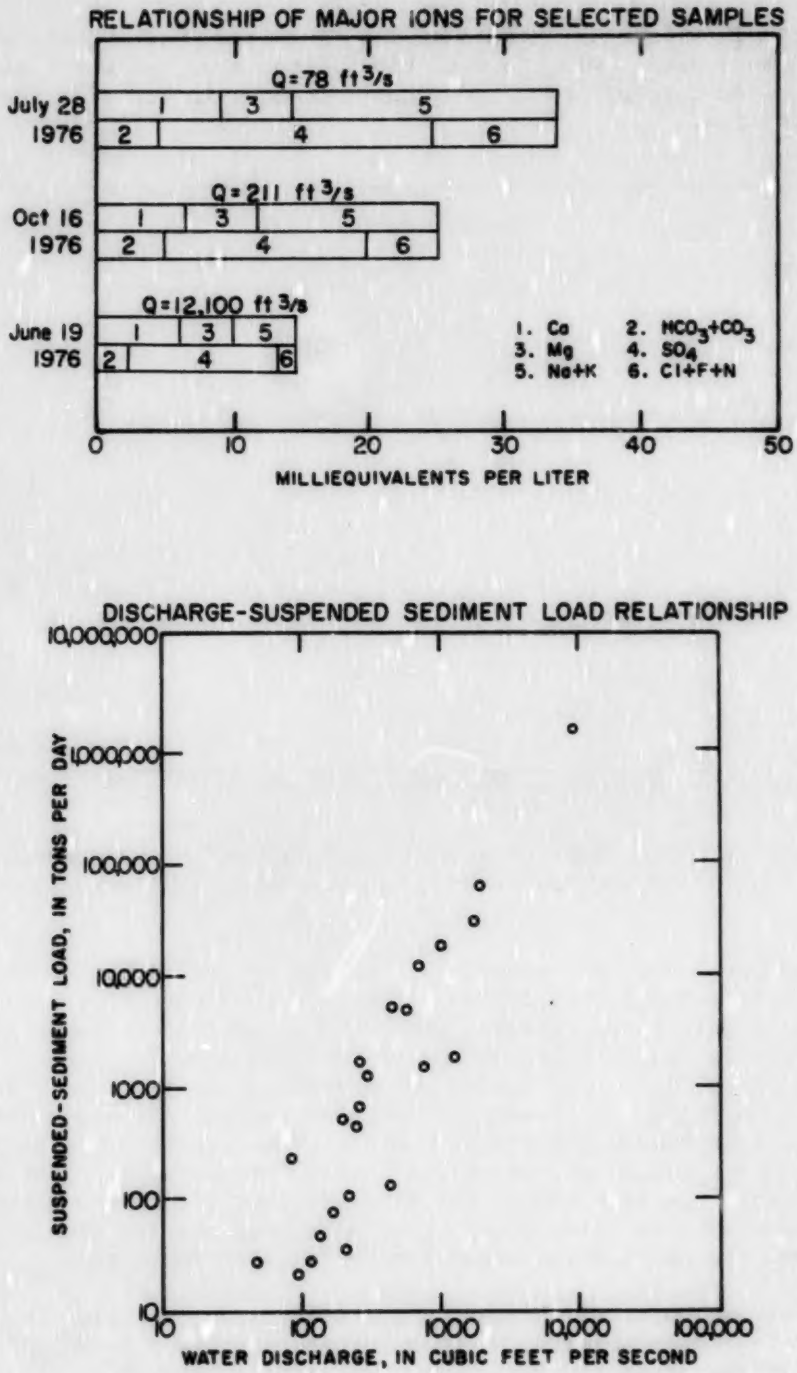


Figure 45.--Hydrographs of stream discharge and suspended-sediment concentration for Powder River at Moorhead, 1975 water year.

The Powder River is a prairie river that is high in concentrations of dissolved solids and sediment; the water is a sodium sulfate type (fig. 46) except during peak-flow periods. Clear Creek, at its confluence with the Powder River, is close to its source of snowmelt and, therefore, is low in concentrations of dissolved solids and sediment; the water is a calcium sulfate type. During spring runoff at Moorhead calcium and magnesium are more predominant than sodium and the percentage of bicarbonate increases slightly. This is the result of the increased flow of mountain tributaries such as Clear Creek. In late summer the flow of Clear Creek, sustained by high mountain snowmelt, is often equal to or more than the low flow of the Powder River; thus, the calcium and magnesium percentages increase.

In contrast to other streams in the study area, chloride is a conspicuous anion in the ionic balance. Concentrations ranged from 0.1 to 320 mg/L with the average being 140 mg/L. The 0.1 mg/L concentration was unusual, occurring during spring runoff, as did the next lowest concentration of 45 mg/L. Chloride was reported by Hembree, Colby, Swenson, and Davis (1952) as being 1 percent of the anions in the water during low flow at Moorhead.



RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES

DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 46.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Powder River at Moorhead (station 31).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	31		44-12100	ft^3/s
Specific conductance (at 25 deg. C)	30	1930	730-2800	umhos/cm
pH	30	8.1	7.5-8.6	units
Temperature	34	8.0	0.0-24.5	deg. C
Turbidity	28	590	7-4200	JTU
Dissolved oxygen	24	89	35-108	percent
Biochemical oxygen demand	28	2.3	.4-5.8	mg/L
Calcium (Ca), dissolved	29	120	50-190	mg/L
Magnesium (Mg), dissolved	29	56	16-91	mg/L
Sodium (Na), dissolved	29	240	74-430	mg/L
Percent sodium	29	48	29-56	percent
Sodium-adsorption ratio	29	4.4	1.8-6.9	---
Potassium (K), dissolved	29	6.8	3.1-17	mg/L
Bicarbonate (HCO_3)	29	274	142-427	mg/L
Carbonate (CO_3)	25	0	0-2	mg/L
Sulfate (SO_4), dissolved	28	630	290-1100	mg/L
Chloride (Cl), dissolved	29	140	.1-320	mg/L
Fluoride (F), dissolved	27	.4	.3-.8	mg/L
Silica (SiO_2), dissolved	29	7.4	3.3-12	mg/L
Dissolved solids (calculated)	28	1360	625-2130	mg/L
Nitrite plus nitrate, total as N	30	.29	.00-.74	mg/L
Nitrogen, ammonia, total as N	30	.08	.00-.24	mg/L
Nitrogen, total organic as N	29	1.9	.11-8.0	mg/L
Nitrogen, total kjeldahl as N	29	2.0	.23-8.1	mg/L
Phosphorus, total as P	30	.51	.00-2.5	mg/L
Suspended sediment	24	---	28-49700	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	4	0-30	9	1300-270000	ug/L
Arsenic	2	0-1	10	0-350	ug/L
Beryllium	2	0-<10	10	0-10	ug/L
Boron	26	70-890	---	---	ug/L
Cadmium	2	0	10	0-20	ug/L
Chromium	2	0-<10	10	0-500	ug/L
Copper	4	2-10	12	10-900	ug/L
Iron	24	0-110	10	2000-600000	ug/L
Lead	4	1-3	12	<100-800	ug/L
Lithium	2	60	10	50-450	ug/L
Manganese	2	0	9	20-1400	ug/L
Mercury	4	.0-4	10	.0-1.1	ug/L
Molybdenum	2	3-<4	10	0-5	ug/L
Nickel	2	2-6	10	<50-650	ug/L
Selenium	3	0-2	12	0-8	ug/L
Vanadium	2	2.1-<6	---	---	ug/L
Zinc	4	0-180	9	30-2700	ug/L

Figure 46.--Continued.

During a similar period of discharge, the percentage now is at least 8 percent and generally higher.

The dissolved-solids concentration fluctuated inversely with the discharge. Clear Creek had a large dilution effect on the quality of the Powder River, owing to its low concentration of dissolved solids. The average concentration of the Powder River for the 1975 water year was 1,930 mg/L at Arvada, Wyo. (above the confluence with Clear Creek), which decreased to 1,140 mg/L at Moorhead. The range in concentration at Moorhead was 625 to 2,130 mg/L. The low values were predominantly from periods of spring runoff. Sulfate, the dominant anion for much of the year, had an average concentration of 630 mg/L.

Dissolved oxygen decreased during periods of ice cover and high runoff. A low of 35 percent saturation was recorded on February 19, 1975, during ice cover. The average percent of oxygen saturation for the period of record was 89. BOD averaged 2.3 mg/L but varied throughout the year, often fluctuating inversely to the oxygen concentration. The highest oxygen demand recorded was 5.8 mg/L during a peak flow on June 19, 1976, when the percent oxygen saturation was 70.

Nutrient concentrations at Moorhead were high relative to most other drainages. Average total phosphorus and total organic nitrogen were 0.51 and 1.9 mg/L, respectively. The high nutrient values correlated well with high discharge and sediment concentrations. Size analyses of selected suspended samples showed that more than 60 percent and at times nearly 100 percent of the sediment was finer than 0.062 millimeter--the sand-silt break. This is especially important in transport of nutrients and other sorbed constituents and to some extent in inhibiting their availability to the immediate environment.

Extensive irrigation is practiced upstream and downstream from the station. Throughout the irrigation period, the dissolved-solids concentrations and SAR values are within ranges that cause medium-high salinity hazards and low sodium hazards. High sediment concentrations during the irrigation season cause nuisance conditions and make water spreading an important means of irrigation.

The plains are the source for most of the sediment transported by the Powder River and its tributaries. The plains are underlain by easily erodible sedimentary rock. Active gully erosion can be seen through most of the basin. Erosion of alluvial deposits along the main stream is also evident. The annual suspended-sediment discharge for the 1975 and 1976 water years was, respectively, 5,681,731 and 3,299,693 tons.

The water quality is closely associated with sediment concentration. All components are in constant interaction with the sediment phase, which serves as a source and sink for the dissolved chemicals and as a means of transport for organics and nutrients. The fluctuation of the sediment concentration is closely related to the discharge as shown in figure 46.

Powder River near Locate

The Powder River near Locate (at station 32) flows through a wide grass- and sage-covered valley. The topography changes to nearly barren shale gullies of badland topography toward the valley's edge and eventually to a sparsely tree-covered highland some distance from the river. The river banks are generally low and consist of easily erodible alluvium.

The Little Powder River and Mizpah Creek both enter the Powder River between the gages at Moorhead and near Locate, where streamflow-record collection began in 1938. Sediment-concentration, water-temperature, and specific-conductance records have been collected periodically since early 1950.

The 1975-water-year hydrograph (fig. 47) shows erratic flow patterns until spring runoff, and then, a relatively smooth recession during the summer. Many of the sharp peaks that were present at Moorhead are moderated at this station. The mean flow of 810 ft^3/s was 30 percent above the 37-year average. Streamflow for the 1976 water year was 8 percent below the average.

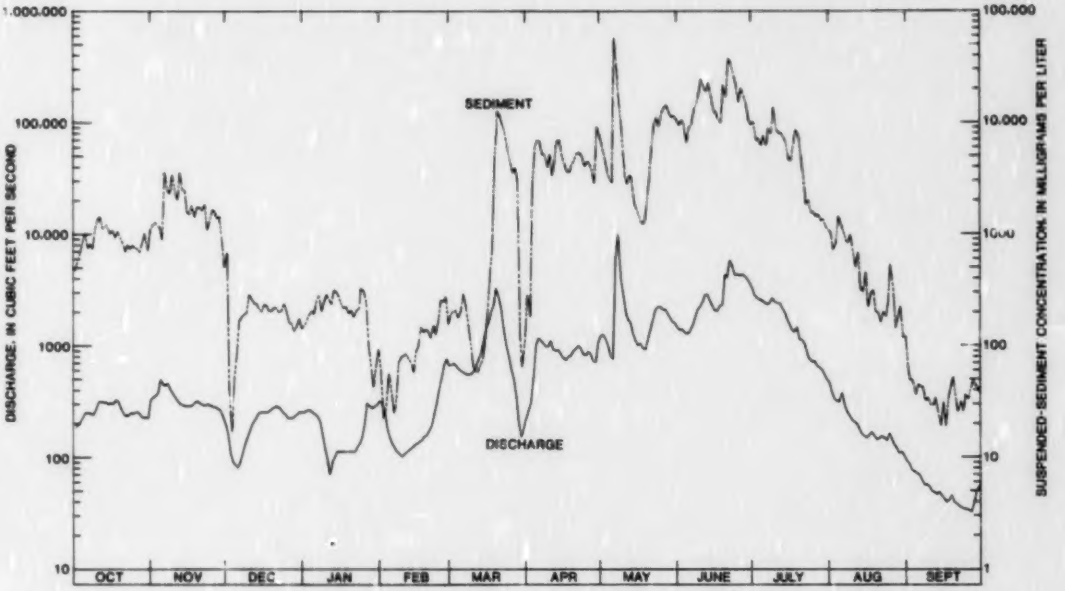
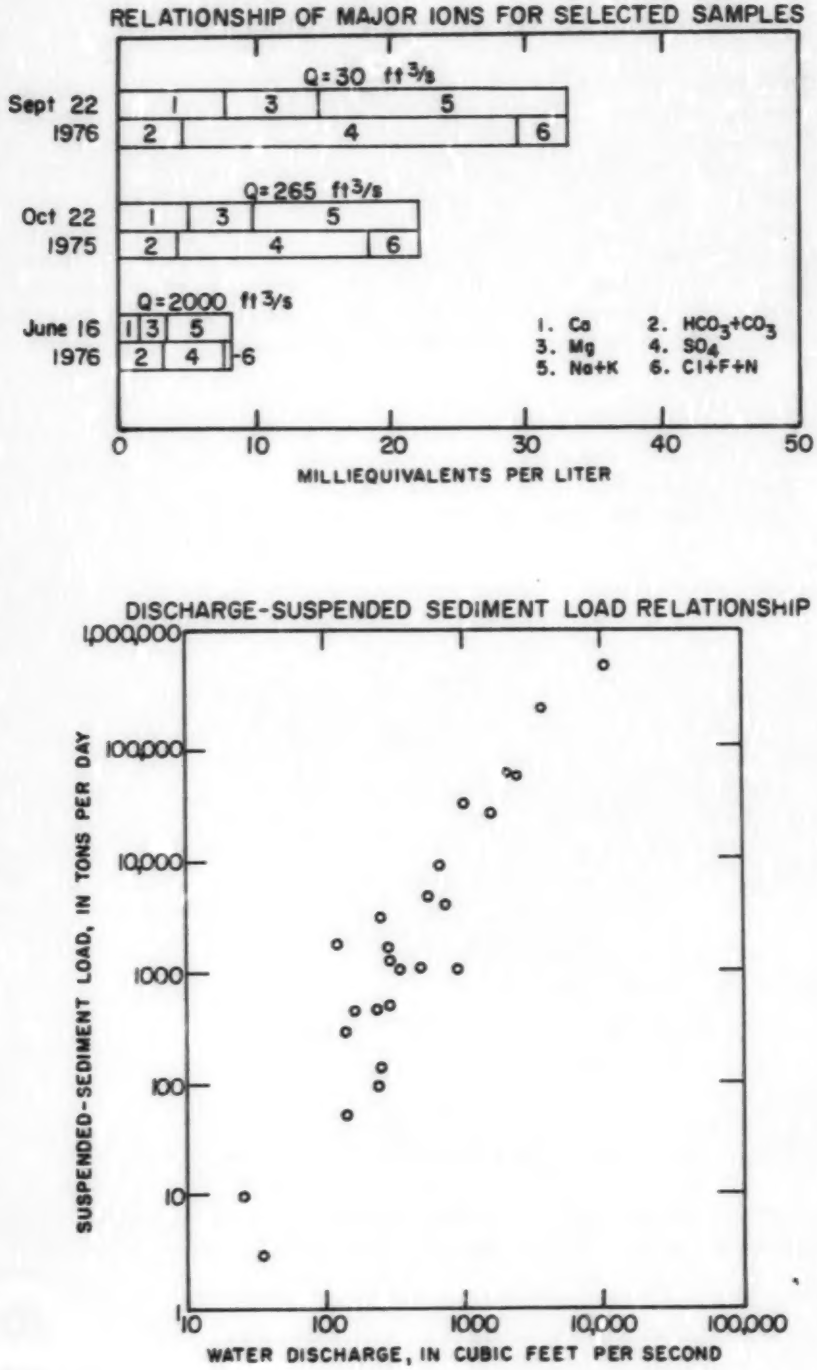


Figure 47.--Hydrographs of stream discharge and suspended-sediment concentration for Powder River near Locate, 1975 water year.

Sodium and sulfate ions dominated the chemical character of water throughout the range of flows (fig. 48). The exposure to shale over large areas may explain the ion stability during low to moderate flows. As was typical at the Moorhead station during the runoff period, calcium, magnesium, and sulfate made up increasing percentages of the cation-anion groups.



RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES

DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 48.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Powder River near Locate (station 32).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	25		30-10800	ft^3/s
Specific conductance (at 25 deg. C)	24	1840	760-2900	umhos/cm
pH	24	8.2	7.7-8.5	units
Temperature	25	8.5	0.0-23.5	deg. C
Turbidity	23	800	4-5800	JTU
Dissolved oxygen	24	88	20-104	percent
Biochemical oxygen demand	5	2.0	.9-3.6	mg/L
Calcium (Ca), dissolved	23	111	48-160	mg/L
Magnesium (Mg), dissolved	23	50	14-87	mg/L
Sodium (Na), dissolved	23	240	110-420	mg/L
Percent sodium	23	51	41-57	percent
Sodium-adsorption ratio	23	4.7	2.7-6.8	---
Potassium (K), dissolved	23	7.0	4.3-12	mg/L
Bicarbonate (HCO_3)	23	275	158-454	mg/L
Carbonate (CO_3)	20	0	0-2	mg/L
Sulfate (SO_4), dissolved	23	620	220-1200	mg/L
Chloride (Cl), dissolved	23	110	23-220	mg/L
Fluoride (F), dissolved	23	.4	.3-.5	mg/L
Silica (SiO_2), dissolved	23	8.4	5.5-12	mg/L
Dissolved solids (calculated)	23	1280	519-2130	mg/L
Nitrite plus nitrate, total as N	23	.33	.00-.74	mg/L
Nitrogen, ammonia, total as N	---	---	---	mg/L
Nitrogen, total organic as N	---	---	---	mg/L
Nitrogen, total kjeldahl as N	23	1.9	.44-7.3	mg/L
Phosphorus, total as P	23	.66	.01-3.1	mg/L
Suspended sediment	25	---	31-19000	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	---	---	---	---	ug/L
Arsenic	8	0-2	8	0-60	ug/L
Beryllium	---	---	---	---	ug/L
Boron	---	---	---	---	ug/L
Cadmium	8	0-1	8	<10-10	ug/L
Chromium	8	0-10	8	0-100	ug/L
Copper	8	2-8	8	10-200	ug/L
Iron	8	10-150	8	1600-170000	ug/L
Lead	8	0-4	8	<100-200	ug/L
Lithium	---	---	---	---	ug/L
Manganese	8	0-10	8	30-3500	ug/L
Mercury	8	.0-.3	8	.1-.3	ug/L
Molybdenum	---	---	---	---	ug/L
Nickel	---	---	---	---	ug/L
Selenium	8	1-3	8	1-5	ug/L
Vanadium	---	---	---	---	ug/L
Zinc	8	0-40	8	50-670	ug/L

Figure 48.--Continued

During spring runoff when a large part of the flow was from snowmelt, the dissolved-solids concentration was at or near the minimum 519 mg/L value as seen in figure 48. Concentrations increased from late summer throughout fall and winter as ground-water inflow accounted for a larger percentage of the flow. The average dissolved-solids concentration for water years 1975-76 was 1,280 mg/L. Within the study area this concentration was surpassed by many of the smaller drainages, but because of their reduced discharges they do not have the impact of the Powder River.

Water temperatures varied directly with air temperature, increasing to as much as the 30°C measured July 26, 1959. The pH ranged from a low of 7.7 to a high of 8.5 but was generally 8.2 to 8.3. The lowest percentage of oxygen saturation was 20 recorded February 19, 1975, during ice cover. During a high flow on June 17, 1975, the dissolved oxygen was 73-percent saturated. Nitrogen concentrations were nearly identical to those at Moorhead and the average total phosphorus increased in value from 0.51 at Moorhead to 0.66 mg/L near Locate.

Water use is primarily for irrigation with small acreages of bottomland irrigated both upstream and downstream from the station. The quality of irrigation water is essentially the same as that described for Moorhead. High salt content of the water requires that excessive water be used for soil leaching. The high sediment content causes irrigation problems.

The Powder River channel is subject to erratic fluctuations in flow and ice breakups that disturb an unstable bottom and increase sediment transport. Sparse plant growth along the river banks and bed has little restraint on erosion. Abundant fine sediment found in the river produces a rather high turbidity, which reduces primary productivity.

Sediment concentration is related to water discharge, but the two are not always correlatable as can be seen from the hydrograph superimposed on the sediment concentration in figure 47. A decrease in sediment in December caused by ice development is interrupted by short winter breakups. Spring thaw and corresponding ice jams and high runoff generally produce the peak sediment discharge and concentration for the year. High flows in summer months caused by intense summer rainstorms can also increase sediment discharge. The annual suspended-sediment discharge at this station can be erratic, as illustrated by the results of the 1975 and 1976 water years. The respective suspended-sediment discharges were 8,687,044 and 3,059,089 tons.

Areal correlation

The water quality of the Powder River at Moorhead and near Locate was similar throughout much of the year. Figure 49A shows the major-ion concentrations for November 19, 1975. The average dissolved-solids concentration for Moorhead and Locate shows a downstream reduction of about 6 percent. In about half the analyses, however, the concentration is higher near Locate than at Moorhead. However, Hembree, Colby, Swenson, and Davis (1952) found that during

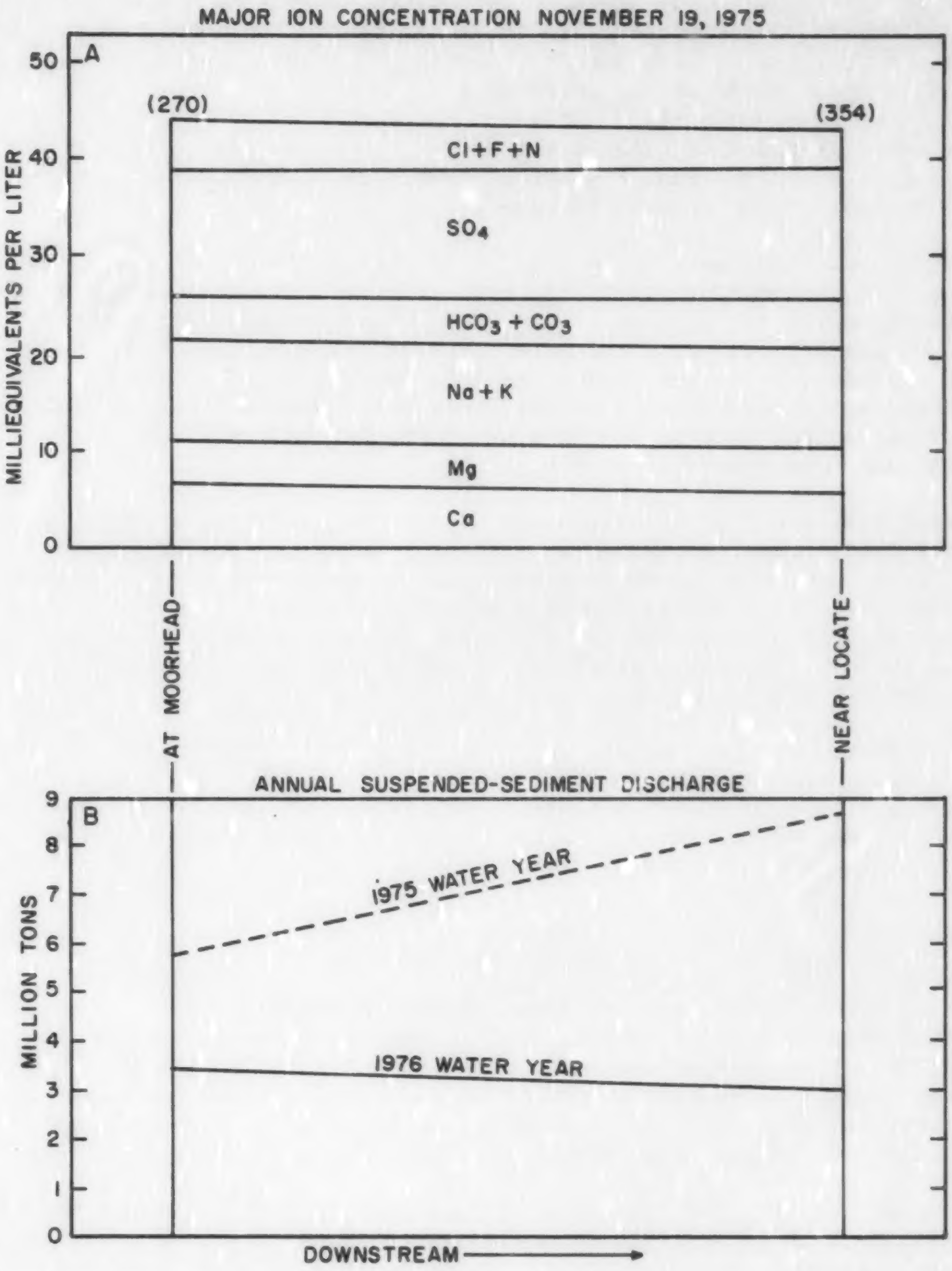


Figure 49.--(A) Concentrations of dissolved constituents and (B) suspended sediment discharges for selected periods on the Powder River. Numbers in parentheses represent stream discharge at time of sampling, in cubic feet per second.

a period of base flow (Sept. 11-14, 1949), dissolved-solids concentration increased by nearly 30 percent between the two sites. This condition was somewhat evident at times of very low flow during the study. The mean values tend to mask these infrequent occurrences.

The chloride concentration in the Powder River was generally high for the study area. For the past 2 years of record the chloride ion averaged about 20 percent of the anionic balance.

The suspended-sediment graph (fig. 49B) differs from those of the other drainages. Measurement of daily duspended sediment at both Powder River stations permits portrayal of annual suspended-sediment discharges for the 2 years. The graph shows an approximate increase of 50 percent from the upstream to downstream station during the 1975 water year. In 1976 the downstream trend was a reduction of nearly 7 percent. Water-discharge records for the 2 years show that annual flow was much above average for the 1975 water year and near average for 1976.

During some years of below-average streamflow, sediment apparently accumulates, with the channel acting as a sediment reservoir. During years (or periods) of high flows the accumulated sediment is re-suspended and transported downstream, thus periodically flushing selected reaches of the river channel. Suspended-sediment movement in the river was erratic, especially at periods of lower streamflow. This was evident from comparison of monthly suspended-sediment loads between stations.

Although the general water quality of the Powder River is not as good as that of other larger streams in southeastern Montana, the river is the lifeline for many ranchers and a wildlife population. Hay is irrigated and the river is used for stock watering. The valley has a large population of wildlife including fish, birds, deer, and antelope.

Mizpah Creek basin

Mizpah Creek, which is 134 miles long and drains 797 mi^2, originates in the uplands west of Broadus (fig. 1). It flows north roughly paralleling the Powder River until its confluence at Mizpah, about 45 miles south of the Yellowstone River. The upper drainage has some tree-covered hills but is mostly grass and sage-covered. The large, steep, barren slopes of shale characteristic of the Powder River area are not common in the Mizpah drainage.

The creek crosses the Fort Union Formation, exposing all three members along its length. The valley alluvium is underlain by the Tongue River and Lebo Shale Members in the upper third of the basin and the Tullock Member downstream to the mouth.

The Mizpah Creek channel is in many places dammed for stock watering. The flow between ponds is often by subsurface only. During the late summer and early fall the creek commonly is dry for several consecutive weeks owing to evaporation and transpiration. Later in the fall when plants become dormant, flow returns.

The creek is used mostly for cattle watering and to a lesser extent for irrigation. Cattle affect the water quality in the sampling areas by trampling in and around the creek, leaving feces, and stripping the vegetation--all of which contribute to the degradation of the water quality. Irrigation water is used mostly for flooding hay meadows and depends upon supply. Many tributary catchment structures and diversions are used to capture irrigation water from surface runoff.

Three water-quality sampling sites (fig. 1) are maintained on Mizpah Creek: at Olive (station 33), near Volborg (station 34), and near Mizpah (station 35). This spacing allows sampling of the water at the headwaters, mid-point, and mouth of the creek. Sampling was initiated in October 1975. The station near the mouth, Mizpah Creek near Mizpah, has been operated as a continuous-recording streamflow station since October 1975.

Mizpah Creek at Olive

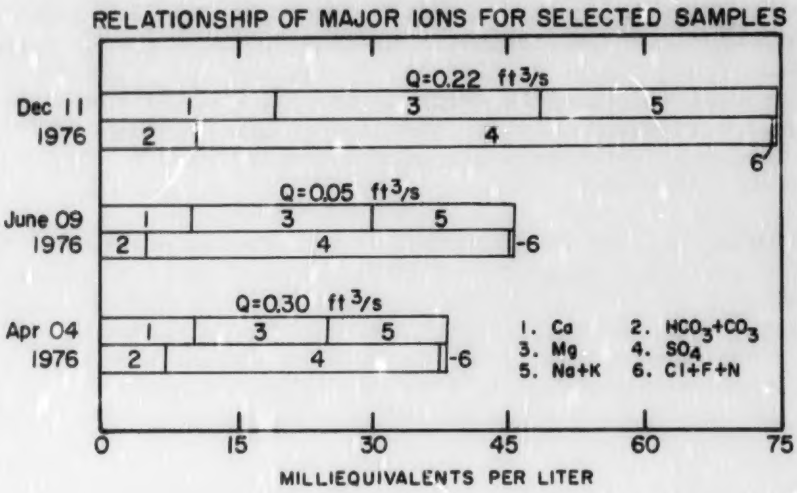
This station has an upstream drainage area of 129 mi^2. The hills near the station are topped with trees, but the valley is covered with grass and sage. The channel is entrenched about 6 feet with wide pools that are choked with cattails and other aquatic growth. The stream is extensively ponded along the upper reach, but had flow at the station much of the year, apparently the result of ground-water inflow. All samples were taken at the outlet of a pond near the site. The maximum flow sampled was 0.37 ft^3/s.

The water consisted of almost equal amounts of magnesium, sodium, and calcium cations. Sulfate averaged 2,300 mg/L, comprising about 80 percent of the anions. As can be seen by the ionic-concentration graph (fig. 50), the ratio of dissolved constituents remained relatively stable throughout the sampling period.

Even though no significant flow was noted during spring runoff, the effects of dilution on the dissolved-solids concentration can be seen in figure 50. In the Mizpah drainage the highest concentration of dissolved solids, 4,800 mg/L, was recorded at this site on November 19, 1975. Dissolved-solids concentration ranged from 2,390 to 4,800 mg/L and was distinctly divided between winter and spring samples. During the winter all samples were greater than 4,000 mg/L. Samples during the spring ranged from 2,390 to 2,880 mg/L.

A strong sulfur smell, which increased in the winter during ice cover, was noted from most samples. The smell was attributed to mercaptan associated with decomposing vegetation in an anaerobic environment.

Nutrients were relatively abundant during winter months when plant decomposition occurred. Dissolved oxygen often decreased to zero and BOD increased. The concentration of ammonia increased as the breakdown of organic nitrogen increased and the nitrifying bacteria were slowed by the decrease in temperature. This process resulted in a total ammonia concentration of 1.2 mg/L February 12, 1976. Aquatic vegetation in the channel was dense during the summer.



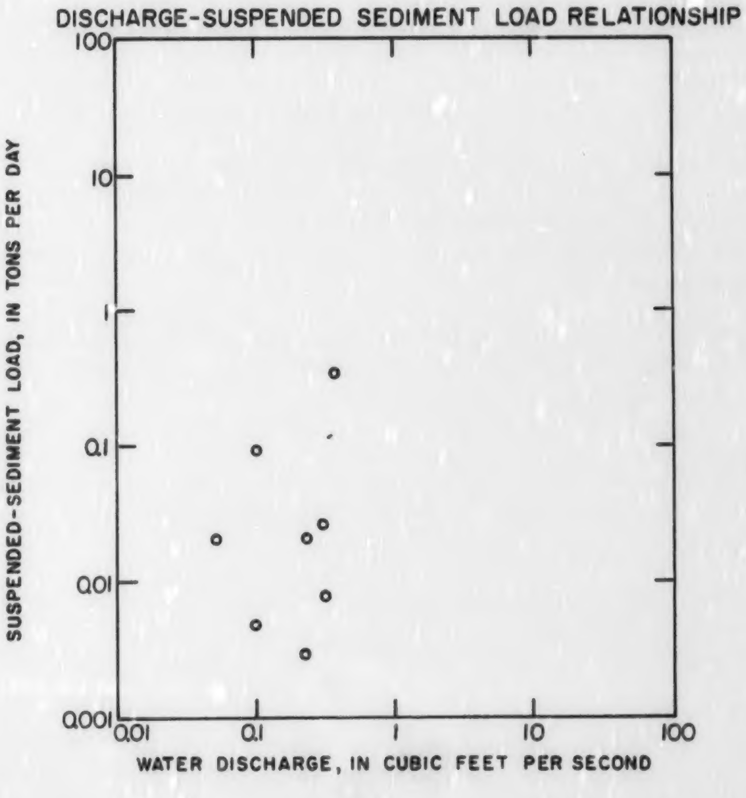


Figure 50.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Mizpah Creek at Olive (station 33).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	8		0.05-.37	ft^3/s
Specific conductance (at 25 deg. C)	8	4140	3000-5570	umhos/cm
pH	8	7.8	7.5-8.1	units
Temperature	8	7.0	0.0-22.5	deg. C
Turbidity	8	2	1-5	JTU
Dissolved oxygen	8	72	0-164	percent
Biochemical oxygen demand	8	2.3	.6-6.9	mg/L
Calcium (Ca), dissolved	8	290	200-380	mg/L
Magnesium (Mg), dissolved	8	270	180-360	mg/L
Sodium (Na), dissolved	8	430	280-600	mg/L
Percent sodium	8	34	32-36	percent
Sodium-adsorption ratio	8	4.4	3.5-5.5	---
Potassium (K), dissolved	8	16	11-22	mg/L
Bicarbonate (HCO_3)	8	519	287-762	mg/L
Carbonate (CO_3)	8	0	0	mg/L
Sulfate (SO_4), dissolved	8	2300	1500-3200	mg/L
Chloride (Cl), dissolved	8	20	3.8-29	mg/L
Fluoride (F), dissolved	8	.3	.2-.4	mg/L
Silica (SiO_2), dissolved	8	11	.4-22	mg/L
Dissolved solids (calculated)	8	3570	2390-4800	mg/L
Nitrite plus nitrate, total as N	8	.02	.00-.04	mg/L
Nitrogen, ammonia, total as N	8	.21	.00-1.2	mg/L
Nitrogen, total organic as N	8	1.3	.91-1.8	mg/L
Nitrogen, total kjeldahl as N	8	1.5	1.0-3.0	mg/L
Phosphorus, total as P	8	.09	.03-.24	mg/L
Suspended sediment	8	128	6-384	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	0	3	20-90	ug/L
Arsenic	1	2	3	1-2	ug/L
Beryllium	1	10	3	0-10	ug/L
Boron	8	0-530	---	---	ug/L
Cadmium	1	0	3	<10	ug/L
Chromium	1	20	3	0-20	ug/L
Copper	1	0	3	10-20	ug/L
Iron	8	40-370	3	180-940	ug/L
Lead	1	1	3	<100-100	ug/L
Lithium	1	110	3	60-120	ug/L
Manganese	1	90	3	60-7100	ug/L
Mercury	1	.0	3	.0	ug/L
Molybdenum	1	1	3	0-1	ug/L
Nickel	1	4	3	<50	ug/L
Selenium	1	0	3	0	ug/L
Vanadium	1	.4	---	---	ug/L
Zinc	1	30	3	0-30	ug/L

Figure 50.--Continued.

Trace-metal concentrations were not unusual except for total manganese, which was the highest for the study area. A total manganese concentration of 7,100 µg/L was recorded for January 15, 1976. A concentration of 3,500 µg/L was found at the Powder River near Locate on June 17, 1975. Both concentrations were associated with high sediment discharge.

Water from Mizpah Creek is little used in the Olive area. The lack of high flows does not permit flood irrigation, which is the predominant method of irrigation in the study area. Also, the high dissolved-solids concentration in the water causes a salinity hazard for irrigation. The dissolved-solids concentrations do not themselves present a hazard to stock; however, sulfate concentration in excess of 2,500 mg/L has been reported by some to be near the tolerable limits (McKee and Wolf, 1971).

The small sediment increases during January and February could have been due to the disruption of very fine sediment on the bottom. The pond immediately above the sampling site provides ample time and space for settling of sediment. The area is heavily used for a cattle crossing, leaving the small channel with a very soft and unconsolidated bottom.

Mizpah Creek near Volborg

The station Mizpah Creek near Volborg at the mid-point of the drainage has a drainage area of 510 mi^2. The stream is entrenched about 10 feet and has banks covered with grass and sage. The point of sampling is between two pools in a channel with a relatively stable gravel bottom. The maximum flow measured during any sampling period was 8.9 ft^3/s on May 10, 1976. Flow generally occurs at this site, except during extremely dry periods. Because ice is rarely found on the flowing section of the stream, ground water with its warmer temperature is believed to be sustaining surface flow.

As shown in figure 51, sodium and sulfate ions dominated the water chemistry and calcium, magnesium, and bicarbonate were present in lesser amounts. The increase in sodium from the station at Olive might be attributed to inflow of ground water from the Tullock Member of the Fort Union Formation.

Dissolved-solids concentrations were generally about 2,000 mg/L. A lower concentration of 888 mg/L was associated with snowmelt that was sampled February 11, 1975. These concentrations are less than those at Olive, probably owing to the reduced contact time in stagnant ponds and the lower dissolved-solids concentration found in water from the Tullock Member.

Dissolved-oxygen saturation varied from 47 to 131 percent. Decomposition of vegetation, ice-covered ponds, and organic-rich spring runoff acted to produce low oxygen concentrations. In summer months warm water, intense sunlight, and abundant algae production, through photosynthetic processes, resulted in high oxygen saturation. BOD concentrations were generally low, averaging 1.9 mg/L, but did reach 6.7 mg/L during the February 13 runoff. Nutrients were generally low during the growing season--probably a result of plant uptake.

Sediment concentrations were low because of well-established vegetation on the banks, the pool-to-pool regime, and low-flow sampling conditions. The largest calculated sediment load was 1.68 tons/day from the May 10, 1976, sample, which had a concentration of 70 mg/L.

A major use of the stream in the area is for stock watering. The water is suitable for stock during all flowing conditions. Although sulfate is a dominant ion, this constituent is not present in amounts that are restrictive to cattle. At best the water might be used to irrigate hay and only then by using the runoff water in which concentrations of dissolved solids are much lower than the average.

Mizpah Creek near Mizpah

This station is located 1 mile above the confluence of Mizpah Creek with the Powder River. The channel is about 20 feet wide and has easily erodible, mostly barren, soil banks about 5 feet high. The creekbed consists of gravel and sand in reaches where the flow is unobstructed and soft mud in ponds which normally dominate the creek.

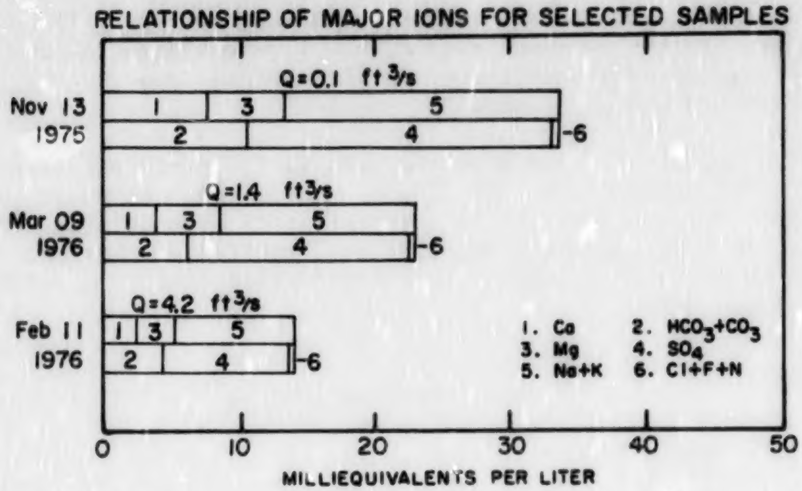
The first year of streamflow measurement (1975 water year) was considered to be a high runoff year, although no-flow conditions were recorded during October and parts of January and September. The peak flow for the year was 1,920 ft^3/s on May 6, 1976. Streamflow generally fluctuates with seasons and local rainstorms, responding to short flashy peaks that may last only a few hours or a few days before returning to reduced flows.

Sodium and sulfate constituted the major ions at this station (fig. 52). These ions were consistently dominant throughout the range of discharges sampled, although bicarbonate was measured at 48 percent during a period of snowmelt runoff. In comparison with the Powder River, bicarbonate concentration was greater and chloride concentration substantially less.

Dissolved-solids concentrations had a wide range, with the low value of 191 mg/L occurring during the February runoff. Fall and winter samples had concentrations that were all near the upper extreme of 2,550 mg/L. Throughout spring and early summer samples showed much fluctuation. During high runoff, water from Mizpah Creek had a diluting effect on the Powder River, but throughout most of the year the opposite was true.

Complete ice cover was common throughout much of the winter. Dissolved oxygen generally fluctuated less than at other Mizpah stations, but supersaturation was found at times--a product of photosynthetic processes from abundant vegetative growth in the pools. The pH values averaged 8.2, which is higher than found at the other two sites on Mizpah Creek. The higher values were generally associated with low flows and the lower values with snowmelt.

Suspended sediment had an important role in the transport of nutrients at this site. Total organic nitrogen reached a concentration of 13 mg/L during



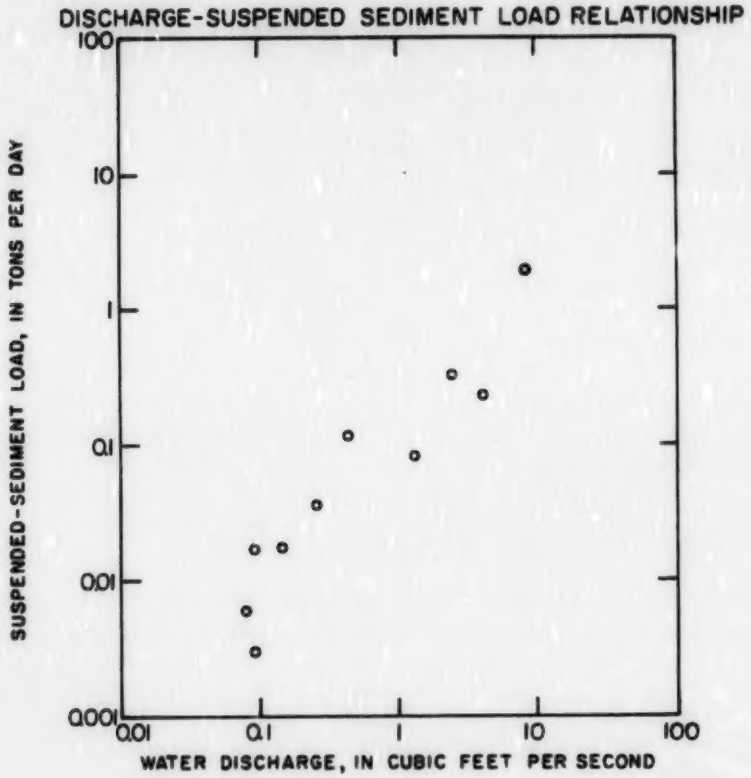
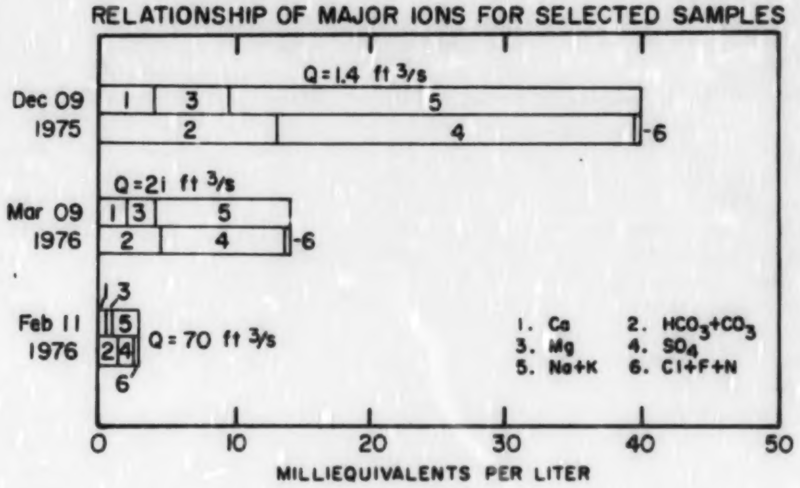


Figure 51.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Mizpah Creek near Volborg (station 34).

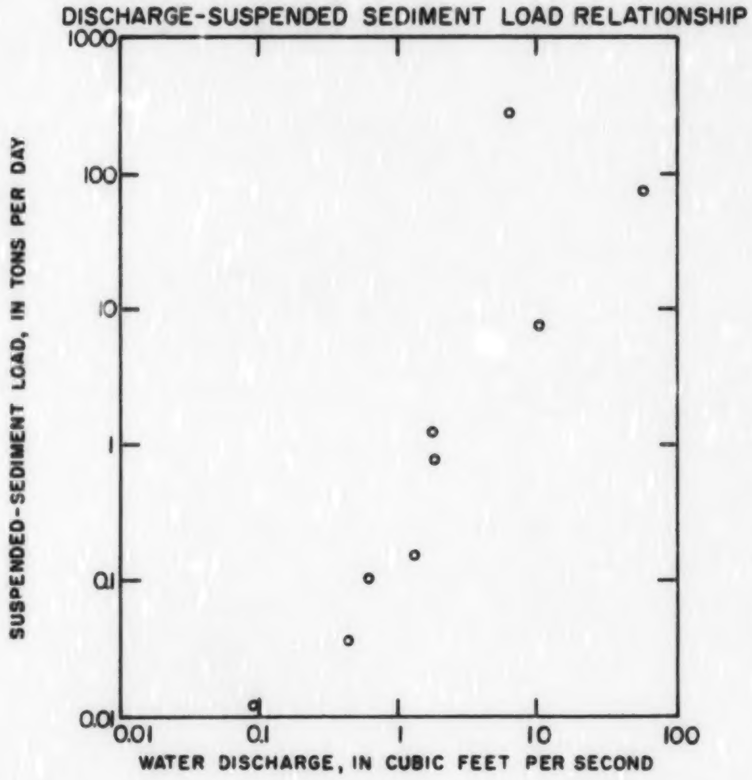
PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	10		0.08-8.9	ft^3/s
Specific conductance (at 25 deg. C)	10	2680	1370-3300	umhos/cm
pH	10	7.9	7.6-8.3	units
Temperature	10	13.5	1.0-29.5	deg. C
Turbidity	10	9	1-30	JTU
Dissolved oxygen	10	90	47-131	percent
Biochemical oxygen demand	10	1.9	.4-6.7	mg/L
Calcium (Ca), dissolved	10	110	45-150	mg/L
Magnesium (Mg), dissolved	10	71	31-87	mg/L
Sodium (Na), dissolved	10	430	200-540	mg/L
Percent sodium	10	62	57-67	percent
Sodium-adsorption ratio	10	7.8	5.6-9.7	---
Potassium (K), dissolved	10	9.9	8.8-12	mg/L
Bicarbonate (HCO_3)	10	517	244-637	mg/L
Carbonate (CO_3)	10	0	0	mg/L
Sulfate (SO_4), dissolved	10	1000	470-1300	mg/L
Chloride (Cl), dissolved	10	8.4	5.8-9.5	mg/L
Fluoride (F), dissolved	10	.3	.2-.4	mg/L
Silica (SiO_2), dissolved	10	10	4.7-16	mg/L
Dissolved solids (calculated)	10	1930	888-2310	mg/L
Nitrite plus nitrate, total as N	10	.01	.00-.03	mg/L
Nitrogen, ammonia, total as N	9	.02	.00-.04	mg/L
Nitrogen, total organic as N	9	.72	.09-1.7	mg/L
Nitrogen, total kjeldahl as N	9	.73	.13-1.7	mg/L
Phosphorus, total as P	10	.05	.00-.16	mg/L
Suspended sediment	10	46	12-92	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	40	4	50-350	ug/L
Arsenic	1	1	4	0-3	ug/L
Beryllium	1	0	4	0-10	ug/L
Boron	10	240-420	---	---	ug/L
Cadmium	1	1	4	<10-20	ug/L
Chromium	1	0	4	0-45	ug/L
Copper	1	0	4	10	ug/L
Iron	10	10-320	4	280-600	ug/L
Lead	1	7	4	<100	ug/L
Lithium	1	40	4	30-40	ug/L
Manganese	1	270	4	150-970	ug/L
Mercury	1	.0	4	.0-.1	ug/L
Molybdenum	1	0	4	0-2	ug/L
Nickel	1	3	4	<50-50	ug/L
Selenium	1	0	4	0-1	ug/L
Vanadium	1	.0	---	---	ug/L
Zinc	1	0	4	0-30	ug/L

Figure 51.--Continued.



RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

Figure 52.--Relationships of major ions, discharge, suspended-sediment load, and analytical values for Mizpah Creek near Mizpah (station 35).

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	9		0.46-70	ft^3/s
Specific conductance (at 25 deg. C)	9	2280	319-4100	umhos/cm
pH	9	8.2	7.5-8.7	units
Temperature	9	11.0	0.0-27.5	deg. C
Turbidity	9	110	5-560	JTU
Dissolved oxygen	9	97	61-128	percent
Biochemical oxygen demand	9	2.9	.6-7.2	mg/L
Calcium (Ca), dissolved	9	47	14-82	mg/L
Magnesium (Mg), dissolved	9	36	5.8-69	mg/L
Sodium (Na), dissolved	9	420	43-720	mg/L
Percent sodium	9	75	59-86	percent
Sodium-adsorption ratio	9	11	2.4-18	---
Potassium (K), dissolved	9	8.1	4.7-13	mg/L
Bicarbonate (HCO_3)	9	423	87-788	mg/L
Carbonate (CO_3)	9	9	0-28	mg/L
Sulfate (SO_4), dissolved	9	820	73-1300	mg/L
Chloride (Cl), dissolved	9	7.6	3.0-13	mg/L
Fluoride (F), dissolved	9	.4	.1-.7	mg/L
Silica (SiO_2), dissolved	9	4.8	1.1-8.3	mg/L
Dissolved solids (calculated)	9	1570	191-2550	mg/L
Nitrite plus nitrate, total as N	9	.23	.00-1.7	mg/L
Nitrogen, ammonia, total as N	8	.15	.01-.98	mg/L
Nitrogen, total organic as N	8	2.6	.60-13	mg/L
Nitrogen, total kjeldahl as N	8	2.7	.61-13	mg/L
Phosphorus, total as P	9	.76	.02-6.0	mg/L
Suspended sediment	9	1960	23-15800	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	1	40	4	380-1200	ug/L
Arsenic	1	1	4	1-3	ug/L
Beryllium	1	0	4	0-20	ug/L
Boron	9	160-450	---	---	ug/L
Cadmium	1	0	4	<10-20	ug/L
Chromium	1	10	4	0-40	ug/L
Copper	1	10	4	10-20	ug/L
Iron	9	0-170	4	380-1400	ug/L
Lead	1	4	4	<100	ug/L
Lithium	1	30	4	20-50	ug/L
Manganese	1	10	4	40-120	ug/L
Mercury	1	.0	4	.0-.1	ug/L
Molybdenum	1	0	4	3-5	ug/L
Nickel	1	9	4	0-50	ug/L
Selenium	1	1	4	0-1	ug/L
Vanadium	1	1.7	---	---	ug/L
Zinc	1	4	4	10-150	ug/L

Figure 52.--Continued.

the period of high-sediment concentration (15,800 mg/L) on June 8, 1976. Total phosphorus had a concentration of 6.0 mg/L at the same time. This value for phosphorus was the highest concentration measured at any site during the study and represents a significant load (218 lb/day) for this small stream. Nutrients were also high during the February runoff. High nutrients were associated with moderately high sediment and organic debris including cattle feces that accumulated near the stream. BOD at this time was 7.2 mg/L and dissolved oxygen dropped to 61 percent of saturation.

Dissolved-boron concentrations averaged 329 µg/L for nine samples and dissolved strontium was 1,100 µg/L for a single sample taken during low flow. Other dissolved metals were relatively low. High concentrations of total iron (1,400 µg/L) and total aluminum (1,200 µg/L) were found in samples for June 13, 1976. Total and dissolved metals were not sampled during the period of high sediment concentration on June 8, 1976.

Stock dams and irrigation diversions are not present in the vicinity of the station. The average dissolved-solids concentration is slightly reduced at this station compared to upstream and uses are the same--primarily stock watering.

Suspended-sediment concentrations at this station had a large range--from 23 to 15,800 mg/L (fig. 52). The maximum sediment concentration was sampled on June 8, 1976, from a moderate flow of 6.7 ft^3/s. The sediment resulted from rainstorms during the previous 2 days. Much of the sediment was from overland runoff in the lower part of the drainage. Sediment concentrations were low and relatively uniform during fall and early winter, and variable the rest of the year.

Areal correlation

The flow of Mizpah Creek is sustained by ground-water inflow throughout most of the year. Significant surface runoff was measured only at the station near Mizpah. Annual mean discharge for Mizpah Creek near Mizpah varied from 33.2 ft^3/s for the 1975 water year to 9.4 ft^3/s for the 1976 water year. Major flows result from snowmelt or local summer rainstorms.

The relative concentrations of the major ions at the three sampling sites on Mizpah Creek are shown in figure 53A. The graph indicates a downstream decrease in dissolved solids, probably due to a combination of evaporation and transpiration from abundant pooling in the upstream reaches and inflow from the Tullock Member of the Fort Union Formation. Soils, as discussed in the Pumpkin Creek drainage, also may be an influencing factor. This downstream reduction in dissolved solids was not always the case; on two occasions in early winter, the Mizpah station had higher dissolved solids than the Volborg station. Evaporation and transpiration were probably greatly reduced and inflow from the Tullock Member was insufficient to cause significant dilution.

Relative changes in major ionic composition correlate well with lithologic units. A downstream increase was noted in percentages of sodium and bicar-

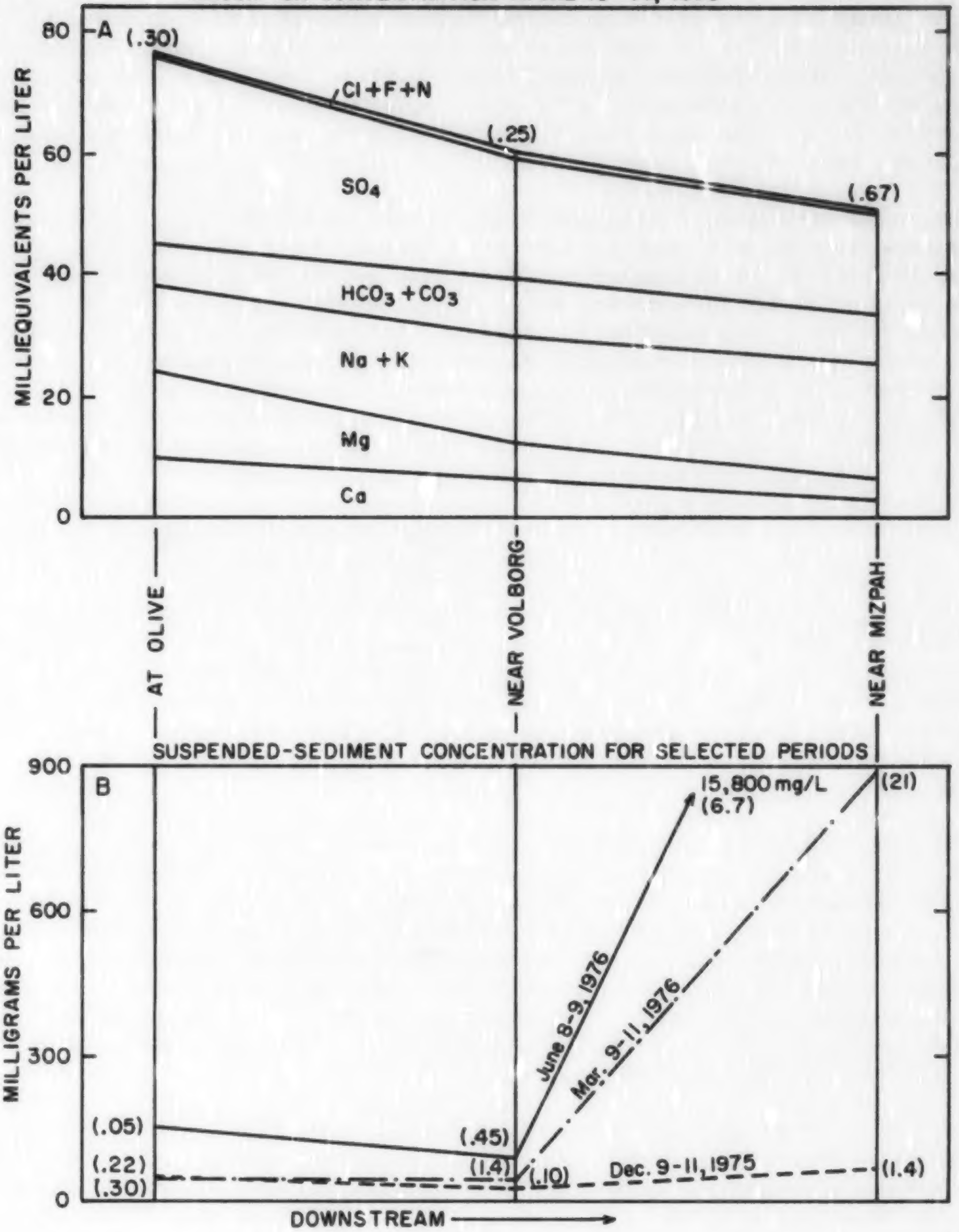


Figure 53.--Concentrations of (A) dissolved constituents and (B) suspended sediment for selected periods on Mizpah Creek. Numbers in parentheses represent stream discharges at time of sampling, in cubic feet per second.

bonate in their respective cation-anion ratios with magnesium and sulfate showing decreases. The changes occur as the stream passes from the Tongue River and Lebo Shale Members to the Tullock Member. Although water from aquifers of the Tullock Member is reported at places to be a sodium bicarbonate type (R. W. Lee, oral commun., 1977) this is one of the few instances in the study area where it was evident.

The sediment-concentration graph (fig. 53B) shows that the lower part of the drainage is the major contributor of sediment, at least during the sampling period. Conditions in the upper drainage such as the pooling nature of the stream, vegetative channel cover, and small discharges are largely responsible for little sediment contribution. Increases in sediment downstream from the Volborg station are associated with higher streamflow that carried sediment to the stream from tributaries, overland runoff, and channel scour. The December 9-11, 1975, samples are indicative of sediment movement at low flows of about 1 ft^3/s or less from near the headwaters to the mouth. Sediment concentrations were relatively low and constant at all stations.

CONCLUSIONS

Streamflow in the area was derived directly from runoff of rainfall and snowmelt or indirectly from water that has passed through the ground-water system and entered the streams as base flow. Surface runoff was generally intense, resulting in high streamflow; base-flow contribution was associated with low flows. Water-quality characteristics often were influenced by whether the water was contributed to the stream as runoff or as base flow; therefore, the characteristics were related to flow conditions.

Throughout much of the study area, the base-flow component was associated with high concentrations of major ions that were dominated by sodium and sulfate. In passage downstream, as the ground-water contribution increased, concentrations of dissolved solids and percentages of sodium and sulfate increased. Of the perennial streams only Rosebud Creek had dominant cations and anions other than sodium and sulfate, although these two ions were present and had the customary downstream increase. The Powder River had relatively small downstream increases in dissolved solids during base-flow periods, and Pumpkin and Mizpah Creeks showed a downstream reduction.

Many of the downstream changes in major ions, rather than being gradual, were rather abrupt and appeared to correlate with changes in lithology. Both sodium and sulfate ions often are associated with clay material and shale. Clay is a common constituent in soils in much of the area and shales are prevalent in all the formations through which the ground water passed. Like the major ions, many of the dissolved minor elements originated in the ground-water system.

Surface runoff, which had no residence time in the ground-water system but extensive contact with soil and vegetation, was characterized by low concentrations of major dissolved ions--generally dominated by calcium or magnesium cations and the bicarbonate anion. This condition was more prevalent in the upper parts of most drainages where gradients were high and the runoff fast. By the time surface runoff had reached the lower drainages, both sodium and sulfate generally had increased. Pumpkin Creek, in contrast to other drainages, often had surface runoff that was dominated by sodium and sulfate.

The presence of calcium and magnesium in surface runoff may be due largely to an absence of other readily soluble cations near the surface. Evidence from the study seems to indicate that sodium has been leached from the surface in many areas and is more available in deeper soil zones. The availability of bicarbonate at or near the surface may result from carbon dioxide provided by the atmosphere and biochemical activity within the soil.

The surface-runoff component also was associated with increased concentrations of several constituents. Contact and removal of organic debris from overland flow caused relatively high values of BOD at most stations. Suspended sediment varied directly with runoff; high flows produced sediment from overland flow, channel scour, and bank erosion. Because of the affinity (sorption) that certain trace elements and nutrients have to clay particles, suspended sediment in turn acted as a transporting mechanism for many of the total constituents. The highest concentrations for some of the total minor elements and nutrients were from samples collected from the Powder River and Mizpah Creek where suspended-sediment concentrations were often higher than concentrations from other streams.

Only during part of the time did base flow and surface runoff individually account for the entire flow of a stream. Often streamflow was a combination of both. Many of the water-quality measurements made during this study reflect this combination. In addition to quality conditions that have been discussed and related to the base-flow and runoff components, all stream water was subject to influences within the channel. Water quality was affected to various degrees by evaporation and transpiration, by reactions of water with mineral solids in the streambed and in suspension, and by aquatic plant and animal life.

Coinciding with all the above natural water-quality conditions are the impacts of man's activities on the streams. The Tongue River Dam and hundreds of small dams, the irrigation practices, and the cattle grazing for many years, all have influenced the quality of the water. The results of this study are an assessment of the water quality in its present state and reflect many natural and some unnatural conditions within the region.

REFERENCES

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water [2d ed]: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.

Hembree, C. H., Colby, B. R., Swenson, H. A., and Davis, J. R., 1952, Sedimentation and chemical quality in the Powder River drainage basin, Wyoming and Montana: U.S. Geol. Survey Circ. 170, 92 p.

Karp, R. W., and Botz, M. K., 1975, Water quality inventory and management plan, middle Yellowstone River basin: Montana Dept. Health and Environmental Sciences, 109 p.

Karp, R. W., Klarich, D. A., and Botz, M. K., 1975, Water quality inventory and management plan, lower Yellowstone River basin: Montana Dept. Health and Environmental Sciences, 177 p.

Lewis, B. D., and Roberts, R. S., 1977, Geology and water-yielding characteristics of rocks of the northern Powder River Basin, southeastern Montana: U.S. Geol. Survey Open-File Rept. 77-75, 22 p.

McKee, J. E., and Wolf, H. W., 1971, Water quality criteria [2d ed]: California State Water Quality Control Board Pub. 3-A, 548 p.

U.S. Geological Survey, 1976, Draft environmental statement, Proposed 20-year plan of mining and reclamation, Westmoreland Resources tract III, Crow Indian ceded area, Montana: U.S. Geol. Survey, 396 p.

______issued annually, Water resources data for Montana: U.S. Geol. Survey open-file repts.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Public Health Service Pub. 956, 61 p.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture Handb. 60, 160 p.

Van Voast, W. A., and Bremmer, J. M., 1976, Volatilization of sulfur from unammended and sulfate treated soils: Soil Biology Biochemistry, v. 8, p. 19-22.

Van Voast, W. A., and Hedges, R. B., 1974, Hydrology of area of Westmoreland Resources tract III coal reserves near Sarpy Creek, southeastern Montana: Montana Bur. Mines and Geology open-file rept., 10 p.

______1975, Hydrogeologic conditions and properties related to mining near Colstrip, southeastern Montana: Montana Bur. Mines and Geology open-file rept., 33 p.

Table 1.--Station descriptions

[Number to left of station name is the same as shown on fig. 1; number to right is formal USGS station number. Station descriptions are in the same order described in the report.]

Station 1 SARPY CREEK NEAR HYSHAM, MT (06294940)

LOCATION.--Lat 46°14'12", long 107°08'03", in SE¼SE¼ sec.30, T.6 N., R.37 E., Treasure County, on left bank 100 ft (30 m) upstream from bridge on FAS Route 415, 0.8 mi (1.3 km) upstream from Hysham Canal, and 5.5 mi (8.8 km) southeast of Hysham.

Station 2 EAST FORK ARMELLS CREEK NEAR COLSTRIP, MT (06294980)

LOCATION.--Lat 45°58'42", long 106°38'38", in SE¼SW¼SW¼ sec.28, T.3 N., R.41 E., Rosebud County, on private road bridge, 0.9 mi (1.4 km) downstream from Corral Creek, and 6.7 mi (10.8 km) north of Colstrip.

Station 3 WEST FORK ARMELLS CREEK NEAR FORSYTH, MT (06294991)

LOCATION.--Lat 46°05'10", long 106°46'09", in SW¼SW¼NW¼ sec.21, T.4 N., R.40 E., Rosebud County, 0.7 mi (1.1 km) upstream from mouth, and 13.5 mi (21.7 km) southwest of Forsyth.

Station 4 ARMELLS CREEK NEAR FORSYTH, MT (06294995)

LOCATION.--Lat 46°14'59", long 106°48'22", in SE¼NW¼NE¼ sec.26, T.6 N., R.39 E., Rosebud County, on right bank 300 ft (90 m) upstream from bridge on Interstate Highway I-94, 2 mi (3 km) upstream from mouth, and 6 mi (10 km) southwest of Forsyth.

Station 5 ROSEBUD CREEK NEAR COLSTRIP, MT (06295250)

LOCATION.--Lat 45°46'03", long 106°34'10", in SE¼SW¼NE¼ sec.8, T.1 S., R.42 E., Rosebud County, on left bank 10 ft (3 m) downstream from bridge on FAS Route 315, 1.5 mi (2.4 km) downstream from Lee Coulee, and 8.4 mi (13.5 km) southeast of Colstrip.

Station 6 GREENLEAF CREEK NEAR COLSTRIP, MT (06295350)

LOCATION.--Lat 45°48'57", long 106°25'08", in NW¼NW¼NW¼ sec.29, T.1 N., R.43 E., Rosebud County, on county road, 0.8 mi (1.3 km) upstream from mouth, and 11.0 mi (17.7 km) southeast of Colstrip.

Station 7 ROSEBUD CREEK ABOVE PONY CREEK, NEAR COLSTRIP, MT (06295400)

LOCATION.--Lat 45°53'33", long 106°24'03", in NE¼SE¼SE¼ sec.29, T.2 N., R.43 E., Rosebud County, on private road bridge, 0.3 mi (0.5 km) upstream from Pony Creek, and 11.6 mi (18.7 km) northeast of Colstrip.

Table 1.--Station descriptions (continued)

Station 8 ROSEBUD CREEK NEAR ROSEBUD, MT (06295500)

LOCATION.--Lat 46°06'46", long 106°27'08", in SW¼NE¼SW¼ sec.12, T.4 N., R.42 E., Rosebud County, on private road bridge, 1.0 mi (1.6 km) downstream from Cottonwood Creek, and 12 mi (19 km) south of Rosebud.

Station 9 ROSEBUD CREEK AT MOUTH, NEAR ROSEBUD, MT (06296003)

LOCATION.--Lat 46°15'53", long 106°28'30", in SW¼NW¼NE¼ sec.21, T.6 N., R.42 E., Rosebud County, on left bank 0.4 mi (0.6 km) upstream from bridge on Interstate Highway I-94, 0.8 mi (1.3 km) upstream from mouth, and 1.6 mi (2.6 km) southwest of Rosebud.

Station 10 TONGUE RIVER AT TONGUE RIVER DAM, NEAR DECKER, MT (06307500)

LOCATION.--Lat 45°08'29", long 106°46'15", in NE¼ sec.13, T.8 S., R.40 E., Big Horn County, on left bank 0.5 mi (0.8 km) downstream from Tongue River Dam, 4 mi (6 km) upstream from Post Creek, 8 mi (13 km) northeast of Decker, 16 mi (26 km) southeast of Kirby, and at mile 162.3 (261.1 km).

Station 11 HANGING WOMAN CREEK NEAR BIRNEY, MT (06307600)

LOCATION.--Lat 45°17'57", long 106°30'28", in N½NW¼SE¼ sec.19, T.6 S., R.43 E., Rosebud County, on right bank 0.5 mi (0.8 km) downstream from bridge on Birney-Otter Road, 1.6 mi (2.6 km) downstream from East Fork, 1.6 mi (2.6 km) south of Birney, and 3.3 mi (5.3 km) upstream from mouth.

Station 12 TONGUE RIVER BELOW HANGING WOMAN CREEK, NEAR BIRNEY, MT (06307610)

LOCATION.--Lat 45°20'19", long 106°31'28", in SW¼SE¼SE¼ sec.1, T.6 S., R.42 E., Rosebud County, at bridge on county road, 1.2 mi (1.9 km) northwest of Birney, 2.5 mi (4.0 km) downstream from Hanging Woman Creek, and at mile 148.8 (239.4 km).

Station 13 OTTER CREEK AT ASHLAND, MT (06307740)

LOCATION.--Lat 45°35'18", long 106°15'17", in NE¼NE¼SE¼ sec.11, T.3 S., R.44 E., Rosebud County, on left bank 200 ft (60 m) downstream from bridge on U.S. Highway 212, 2.5 mi (4.0 km) upstream from mouth and 0.3 mi (0.5 km) southeast of Ashland.

Station 14 TONGUE RIVER BELOW BRANDENBERG BRIDGE, NEAR ASHLAND, MT (06307830)

LOCATION.--Lat 45°52'18", long 106°11'17", in NE¼SW¼NW¼ sec.6, T.1 N., R.45 E., Custer County, on left bank 3.1 mi (5.0 km) downstream from Goodale Creek, 6.5 mi (10.5 km) downstream from Brandenberg Bridge, and 21 mi (33.8 km) north of Ashland.

Table 1.--Station descriptions (continued)

Station 15 TONGUE RIVER AT MILES CITY, MT (06308500)

LOCATION.--Lat 46°21'30", long 105°48'24", in SE¼ sec.23, T.7 N., R.47 E., Custer County, on right bank 4 mi (6.4 km) south of Miles City and 8 mi (12.9 km) upstream from mouth.

Station 16 SQUIRREL CREEK NEAR DECKER, MT (06306100)

LOCATION.--Lat 45°03'05", long 106°55'36", in NW¼NW¼ sec.14, T.9 S., R.39 E., Big Horn County, at gaging station 0.4 mi (0.6 km) upstream from Powers Cormack ditch, 0.5 mi (0.8 km) northwest of CX Ranch, 4 mi (6.4 km) northwest of Decker and 7 mi (11 km) upstream from mouth.

Station 17 DEER CREEK NEAR DECKER, MT (06306800)

LOCATION.--Lat 45°03'19", long 106°42'09", in NW¼SW¼SW¼ sec.10, T.9 S., R.41 E., Big Horn County, at county road bridge, 6.1 mi (9.8 km) upstream from mouth and 8.5 mi (13.7 km) northeast of Decker.

Station 18 FOURMILE CREEK NEAR BIRNEY, MT (06307510)

LOCATION.--Lat 45°12'28", long 106°42'52", in NE¼NW¼NE¼ sec.28, T.7 S., R.41 E., Rosebud County, on dirt road, 0.9 mi (1.4 km) upstream from mouth and 12.5 mi (20.1 km) southwest of Birney.

Station 19 BULL CREEK NEAR BIRNEY, MT (06307530)

LOCATION.--Lat 45°17'17", long 106°35'55", in NE¼SW¼NW¼ sec.28, T.6 S., R.42 E., Rosebud County, 0.4 mi (0.6 km) upstream from mouth and 4.8 mi (7.7 km) southwest of Birney.

Station 20 COOK CREEK NEAR BIRNEY, MT (06307615)

LOCATION.--Lat 45°22'39", long 106°29'45", in SW¼NE¼NW¼ sec.25, T.5 S., R.42 E., Rosebud County, on dirt road, 0.1 mi (0.2 km) upstream from mouth and 3.8 mi (6.1 km) north of Birney.

Station 21 BEAR CREEK AT OTTER, MT (06307670)

LOCATION.--Lat 45°12'20", long 106°12'15", in NW¼NE¼ sec.27, T.7 S., R.45 E., Powder River County, 500 ft (150 m) west of Otter Post Office and 2.6 mi (4.2 km) upstream from mouth.

Station 22 THREEMILE CREEK NEAR ASHLAND, MT (06307730)

LOCATION.--Lat 45°30'46", long 106°09'25", in NW¼SE¼SE¼ sec.3, T.4 S., R.45 E., Rosebud County, on dirt road, 1.5 mi (2.4 km) upstream from mouth and 7.6 mi (12.2 km) southeast of Ashland.

Table 1.--Station descriptions (continued)

Station 23 BEAVER CREEK NEAR ASHLAND, MT (06307810)

LOCATION.--Lat 45°47'52", long 106°14'17", in NW¼SE¼NE¼ sec.34, T.1 N., R.44 E., Rosebud County, at county road bridge, 0.8 mi (1.3 km) upstream from mouth and 14.7 mi (23.7 km) north of Ashland.

Station 24 LISCOM CREEK NEAR ASHLAND, MT (06307840)

LOCATION.--Lat 45°54'09", long 106°09'51", in SE¼NW¼NW¼ sec.27, T.2 N., R.45 E., Custer County, at county road bridge, 0.8 mi (1.3 km) upstream from mouth and 21 mi (34 km) northeast of Ashland.

Station 25 FOSTER CREEK NEAR VOLBORG, MT (06307890)

LOCATION.--Lat 46°01'53", long 105°57'07", in NE¼SE¼NW¼ sec.12, T.3 N., R.46 E., Custer County, 0.6 mi (1.0 km) upstream from mouth and 18.5 mi (29.8 km) northwest of Volborg.

Station 26 PUMPKIN CREEK NEAR SONNETTE, MT (06308080)

LOCATION.--Lat 45°32'20", long 105°49'03", in NE¼SE¼SE¼ sec.29, T.3 S., R.48 E., Powder River County, at bridge on U.S. Highway 212, 5.9 mi (9.5 km) upstream from Winter Gulch and 9.1 mi (14.6 km) north of Sonnette.

Station 27 PUMPKIN CREEK NEAR LOESCH, MT (06308160)

LOCATION.--Lat 45°42'40", long 105°43'50", in NW¼ sec.31, T.1 S., R.49 E., Powder River County, at bridge on county road, 0.9 mi (1.4 km) northeast of Loesch, and 9 mi (14.5 km) upstream from Little Pumpkin Creek.

Station 28 LITTLE PUMPKIN CREEK NEAR VOLBORG, MT (06308170)

LOCATION.--Lat 45°46'00", long 105°46'42", in NE¼SE¼NE¼ sec.10, T.1 S., R.48 E., Powder River County, at county bridge 1.1 mi (1.8 km) upstream from Harkan Creek, 6.9 mi (11.1 km) southwest of Volborg, and 7.7 mi (12.4 km) upstream from mouth.

Station 29 PUMPKIN CREEK NEAR VOLBORG, MT (06308190)

LOCATION.--Lat 45°51'50", long 105°40'10", in W½ sec.5, T.1 N., R.49 E., Custer County, at bridge on U.S. Highway 212, 1.5 mi (2.4 km) upstream from Basin Creek and 1.6 mi (2.6 km) northeast of Volborg.

Station 30 PUMPKIN CREEK NEAR MILES CITY, MT (06308400)

LOCATION.--Lat 46°13'42", long 105°41'24", in SE¼NW¼SW¼ sec.35, T.6 N., R.48 E., Custer County, on right bank 30 ft (9 m) upstream from bridge on U.S. Highway 312, 7.5 mi (12.1 km) upstream from mouth, and 16 mi (26 km) southeast of Miles City.

Table 1.--Station descriptions (continued)

Station 31 POWDER RIVER AT MOORHEAD, MT (06324500)

LOCATION.--Lat 45°04'04", long 105°52'10", in NW¼SE¼NW¼ sec.8, T.9 S., R.48 E., Powder River County, at bridge on county road, 1.1 mi (1.8 km) upstream from discontinued post office at Moorhead, 1.2 mi (1.9 km) upstream from present gage, and 4.0 mi (6.4 km) north of Wyoming-Montana State line.

Station 32 POWDER RIVER NEAR LOCATE, MT (06365000)

LOCATION.--Lat 46°26'56", long 105°18'44", in NW¼SW¼ sec.14, T.8 N., R.51 E., Custer County, at gaging station 1.5 mi (2.4 km) downstream from bridge on U.S. Highway 12 at present site of Locate, 1.5 mi (2.4 km) upstream from Locate and 25 mi (40 km) east of Miles City.

Station 33 MIZPAH CREEK AT OLIVE, MT (06326050)

LOCATION.--Lat 45°32'30", long 105°31'40", in SW¼ sec.26, T.3 S., R.50 E., Powder River County, at bridge on U.S. Highway 212 at Olive, approximately 1 mi (1.6 km) downstream from YT Creek.

Station 34 MIZPAH CREEK NEAR VOLBORG, MT (06326200)

LOCATION.--Lat 45°56'00", long 105°23'40", in SW¼ sec.9, T.2 N., R.51 E., Custer County, at bridge on county road, approximately 2 mi (3.2 km) downstream from Spring Creek and 15.1 mi (24.3 km) northeast of Volborg.

Station 35 MIZPAH CREEK NEAR MIZPAH, MT (06326300)

LOCATION.--Lat 46°15'39", long 105°17'34", in NW¼NE¼SW¼ sec.24, T.6 N., R.51 E., Custer County, on left bank 10 ft (3 m) upstream from county bridge, 1.0 mi (1.6 km) upstream from mouth, and 1.6 mi (2.6 km) northwest of Mizpah.